

SHIP PRODUCTION

SECOND EDITION

BY

RICHARD LEE STORCH, COLIN P. HAMMON,
HOWARD M. BUNCH, & RICHARD C. MOORE



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CONTENTS

LIST OF PLATES, FIGURES, AND TABLES	xi
PREFACE	xix
I. INTRODUCTION	3
The Shipbuilding Process, 3	
Shipbuilding Terms and Definitions, 6	
Ship Definitions, 6	
Ship Types, 6	
Shipyards Facilities, 6	
Organization, 7	
Trades, 11	
Classification Societies and Regulatory Agencies, 13	
Status of the Shipbuilding Industry, 14	
The World Shipbuilding Market, 15	
The U.S. Shipbuilding Industry, 18	
The U.S. Shipbuilding Market, 21	
Resource Markets, 23	
Industry Organization and Performance, 25	
Technology Developments and Productivity, 28	
References, 29	
II. SHIPBUILDING MANAGEMENT THEORY	31
Introduction, 31	
Shipbuilding Economic Theory, 31	
The Shipbuilding Model, 33	
Graphical Analysis of the Shipbuilding Model, 37	
Summary of the Shipbuilding Model, 43	
The Shipbuilding Model: An Example, 44	

Group Technology, 45	
Group Technology, an Overview, 46	
Group Technology Defined, 47	
Classification and Coding, 49	
Group Technology and the Shipbuilding Model, 51	
Work Breakdown Structures, 53	
Systems-Oriented Work Breakdown Structure, 54	
Product-Oriented Work Breakdown Structure (PWBS), 54	
References, 59	

III. PRODUCT-ORIENTED WORK BREAKDOWN STRUCTURE 60

Introduction, 60	
Planning for Production, 61	
Design and Material Definition, 62	
Production, 63	
Controlling, 66	
Costing, 67	
Zone Construction Method, 67	
Hull Block Construction Method (HBCM), 68	
Zone Outfitting Method, 76	
Zone Painting Method, 89	
Pipe Piece Family Manufacture, 93	
Work Lots, 94	
Material Receiving, 95	
Pipe Piece Fabrication, 97	
Pipe Piece Assembly, 99	
Pipe Piece Joining, 103	
Testing and Coating, 103	
Palletizing, 104	
References, 104	

IV. METAL MANUFACTURING AND CONSTRUCTION PROCESSES 105

Hull Materials, 105	
Structure of Metals, 105	
Phase Diagram of Steel, 107	
Properties of Steel, 110	
Types of Shipbuilding Steel, 112	
Aluminum and Aluminum Alloys, 112	
Metal Processes, 116	
Straightening of Plates and Sections, 116	
Cutting, 117	
Forming, 120	
Welding, 123	

Welding Processes, 126	
Soldering and Brazing, 134	
Distortion Removal, 135	
Outfit Processes, 136	
Machinery, 137	
Piping, 138	
Heating, Ventilation, Air-Conditioning (HVAC), 140	
Electrical, 141	
Accommodations, 142	
Deck Fittings, 142	
Combat Systems, 142	
Material-Handling Processes, 143	
Material-Handling Equipment, 143	
Material-Handling System Design, 148	
Rigging, 148	
Staging/Scaffolding, 149	
Surface Preparation and Coating, 150	
Surface Preparation, 150	
Shop Priming, 156	
Coating Systems, 156	
Flame-Sprayed Coating, 157	
Quality Assurance, 158	
Steel Process Quality Assurance, 158	
Outfit Process Quality Assurance, 159	
Test and Trials, 159	
Vessel Delivery Certificates, 160	
References, 160	

V. SHIPYARD LAYOUT

161

Historical Perspective, 161	
Pre-World War II, 162	
World War II—1960, 162	
1960—Present, 163	
Shipyards Facilities and Siting, 168	
General Yard Layout, 170	
Building Positions, 171	
Material Handling, 173	
Warehousing Facilities, 174	
Production Facilities, 175	
Process Lanes, 189	
Physical Process Lanes, 189	
Process Lane Loading, 193	
References, 194	

VI. SHIP DESIGN AND ENGINEERING	195
Introduction, 195	
Design Cycle, 195	
Information Flow, 197	
GT Shipbuilding Impact on Design/Engineering, 199	
Design Stages, 200	
Basic Design, 200	
Functional Design, 203	
Transition Design, 213	
Work Instruction Design, 218	
Mold Loft Interface, 222	
Design and Engineering for Production, 222	
General Principles, 227	
Standardization, 228	
Logic of Design, 229	
Design Changes, 240	
CAD/CAM, 244	
Hardware and Software, 245	
CAD Outputs, 246	
CAD/CAM Potential, 247	
Models, 248	
References, 250	
VII. PLANNING, SCHEDULING, AND PRODUCTION CONTROL	252
Introduction, 252	
Planning and Production Organizations, 252	
Integration with Other Shipbuilding Functions, 252	
Networks, 253	
Activity Durations, 257	
Planning Overview, 257	
Shipyard Planning Overview, 257	
Project Planning and Scheduling Overview, 259	
Planning and Scheduling, 271	
Hull Construction Planning, 272	
Basic Planning and Scheduling, 279	
Detail Work Instruction Planning and Scheduling, 284	
Shop-Level Planning and Scheduling, 293	
Production Control, 298	
Man-hour Expenditures, 298	
Production Progress, 298	
Productivity Indices, 299	
Zone to System Transposition, 302	

PLATES, FIGURES, AND TABLES

Plates

All plates follow page 84.

- I Fig 3-27. Outfit units. (a) An engine room tank top unit. (b) Pumps, valves, pipe pieces, and foundations incorporated as a unit. (c) Pneumatic tubing and supports form a small unit. Fig 3-28 (a & b) Typical machinery outfit units (the same problem area). Fig 3-29. Machinery outfit unit assembled on a common foundation (courtesy Avondale Shipyard).
- II Fig 3-35. Engine room tank top components fitted on-block. Fig 3-36. Outfitted engine room blocks erected over previously landed outfit units (courtesy Avondale Shipyard) Fig 3-37 Down-hand outfitting on-block, in an upside-down block Fig 3-38. On-block outfitting and painting, on the ceiling and on the deck Fig 3-39 Two complex blocks, outfitted together, upside down, to ease erection Fig 3-40. On-board outfitting performed prior to landing the main engine
- III Fig 3-47 On-block outfitting of a forecastle deck upside down. Fig 3-48. On-block outfitting of a forecastle deck right side up. Fig 3-49. On-block outfitting of a side shell and engine room flat upside down. Fig 3-50. On-block outfitting of a side shell and engine room flat right side up Fig 3-51. On-block outfitting of the block shown in figures 3-49 and 3-50 being completed right side up next to the building dock. Fig 3-52. Erection of the block shown in figures 3-49 through 3-51
- IV. Fig 3-53. On-block outfitting of one-half of a superstructure deck Fig 3-54 On-block outfitting of another superstructure deck block Zone, problem area, and stage are the same as in figure 3-53. Fig 3-55 Grand-block joining of the aft half of the superstructure Fig 3-56 Erection, keel laying plus 11 workdays. Fig 3-57 Erection, keel laying plus 13 workdays.
- V. Fig 3-58 Erection, keel laying plus 15 workdays Fig 3-59. Erection, keel laying plus 19 workdays Fig 3-60 Erection, keel laying plus 22 workdays Fig 3-61. Erection, keel laying plus 22 workdays Fig 3-62. Erection, keel laying plus 24 workdays Fig 3-63. Erection, keel laying plus 24 workdays.
- VI. Fig 3-64 Erection, keel laying plus 27 workdays Fig 3-65 Erection, keel laying plus 28 workdays Fig 3-66 Erection, keel laying plus 29 workdays Fig 3-67. Erection, keel laying plus 29 workdays. Fig 3-68 Operation and test (vessel launched 43 workdays after keel laying, delivered seven months after starting fabrication).

Figures

- | | | | |
|-------|---|-------|--|
| 1-1. | Basic ship dimensions and definitions, 7 | 3-7. | Hull block construction method (HBCM) manufacturing levels, 69 |
| 1-2. | Ship types, 8 | 3-8. | HBCM classification by product aspects, 71 |
| 1-3. | Inboard profiles of major ship types, 9 | 3-9. | Parts fabrication problem area and stage classifications, 72 |
| 1-4. | Representative shipyard layout, 12 | 3-10. | Part assembly level classification, 72 |
| 1-5. | World shipbuilding market cycles, 16 | 3-11. | Sub-block assembly level examples, 73 |
| 1-6. | Locations of U.S. shipyards, 20 | 3-12. | Block assembly problem area and stage classifications, 75 |
| 2-1. | Production plan for traditional ship construction, 33 | 3-13. | Semi-block and block assembly, showing the bottom center block of a cargo hold, 76 |
| 2-2. | Sample ship production progress curve, 34 | 3-14. | Block assembly and grand-block joining, showing the top of a wing tank, 77 |
| 2-3. | Shift in the average cost curve when required output changes, 39 | 3-15. | Semi-block and block assembly, showing a bottom wing tank side shell with hopper and the transverse hopper in a cargo hold, 77 |
| 2-4. | Shifts in the average cost curve with changes in labor quality, 40 | 3-16. | Block assembly and grand-block joining, showing a corrugated transverse bulkhead and a deck center between cargo holds, 78 |
| 2-5. | Bottlenecks increase costs and reduce the optimal rate of production, 40 | 3-17. | Block assembly and grand-block joining, showing a cant block, 78 |
| 2-6. | Production plans before and after total output adjustment, 42 | 3-18. | Block assembly, showing an upper deck and an engine room flat, 79 |
| 2-7. | Manpower profiles in an environment of changing requirements, 45 | 3-19. | Semi-block and block assembly, showing a bulbous bow, 79 |
| 2-8. | Comparison of conventional and group process batch flow, 47 | 3-20. | Semi-block and block assembly, showing a forecandle and the upper deck in a fore body, 80 |
| 2-9. | Company functions affected by group technology, 50 | 3-21. | Grand-block joining, showing a forecandle and the upper deck in a fore body, 80 |
| 2-10. | The Boeing Company group technology classification system, based on the E.G. Brisch concept, 52 | 3-22. | Block assembly and grand-block joining, showing the bottom of an engine room, 81 |
| 2-11. | Example of U.S. Navy hierarchical subdivisions, 55 | 3-23. | Block assembly, showing the side shell of an engine room, 81 |
| 2-12. | Product work breakdown structure components, 56 | 3-24. | Zone outfitting method (ZOFM) manufacturing levels, 83 |
| 2-13. | Elements of the three-dimensional PWBS matrix, 57 | 3-25. | ZOFM classification by product aspects, 85 |
| 2-14. | Impacts of time, units of resources, and quality of work circumstance on productivity value, 58 | 3-26. | Problem area subdivisions for design and material requirements for component procurement, 86 |
| 2-15. | Optimum PV requires balanced influences of T, N, and Q, 58 | 3-27. | See Plate I. |
| 2-16. | Iterative development of work packages, 58 | 3-28. | See Plate I |
| 3-1. | Industrial project management cycle, 62 | 3-29. | See Plate I |
| 3-2. | System and zone orientations in the management cycle, 62 | 3-30. | Engine room outfit unit, 87 |
| 3-3. | Design process, 64 | 3-31. | A hatch cover and coaming unit, 87 |
| 3-4. | Design outfit specialty groups, 64 | 3-32. | Very complex piping units, for the deck of a product tanker, 87 |
| 3-5. | Process lanes for simultaneous hull construction and outfitting, 65 | | |
| 3-6. | Integrated schedules for hull construction, outfitting, and painting, 66 | | |

- 3-33 Mast units, 87
- 3-34 On-block outfitting in a pipe tunnel under a cargo hold, 88
- 3-35 See Plate II
- 3-36 See Plate II
- 3-37 See Plate II
- 3-38 See Plate II
- 3-39 See Plate II
- 3-40 See Plate II
- 3-41 Zone painting method (ZPTM) manufacturing levels, 90
- 3-42 ZPTM classification by product aspects, 91
- 3-43 Typical paint systems applied in accordance with ZPTM, 92
- 3-44 A center deck and center transverse bulkhead grand block, upside down, 94
- 3-45 A grand block, including the side shell, top side tank, transverse hopper, and side transverse bulkhead of a cargo hold, 94
- 3-46 The same grand block as in figure 3-45, 94
- 3-47 See Plate III
- 3-48 See Plate III
- 3-49 See Plate III
- 3-50 See Plate III
- 3-51 See Plate III
- 3-52 See Plate III
- 3-53 See Plate IV
- 3-54 See Plate IV
- 3-55 See Plate IV
- 3-56 See Plate IV
- 3-57 See Plate IV
- 3-58 See Plate V
- 3-59 See Plate V
- 3-60 See Plate V
- 3-61 See Plate V
- 3-62 See Plate V
- 3-63 See Plate V
- 3-64 See Plate VI
- 3-65 See Plate VI
- 3-66 See Plate VI
- 3-67 See Plate VI
- 3-68 See Plate VI
- 3-69 Pipe piece family manufacturing method (PPFM) manufacturing levels, 95
- 3-70 PPFM classification by product aspects, 96
- 3-71 Problem area subdivisions for pipe piece fabrication, assembly, and joining levels, 97
- 3-72 Typical classifications for PPFM, 98
- 3-73 Typical decision logic for determining pipe piece families, 99
- 3-74 Typical PPFM classifications, 100
- 3-75 Typical PPFM classifications, 101
- 3-76 Typical PPFM classifications of penetrations, 102
- 3-77 Pipe piece assembly work stations, 102
- 3-78 Pipe piece coating, 102
- 3-79 Pipe piece pallets and pallet storage areas, 103
- 4-1 Arrangement of atoms in cubic lattices, 106
- 4-2 Dendritic crystal growth schematic, 107
- 4-3 Grain boundaries of dendritic crystals, 107
- 4-4 Iron/iron carbide phase diagram, 108
- 4-5 Structural changes in 0.40% carbon steel during slow cooling, 109
- 4-6 Stress-strain curve, 111
- 4-7 S-N plot of fatigue test results, 111
- 4-8 Diagram illustrating plate being straightened in roll-straightener, 116
- 4-9 Diagram illustrating the straightening of thin plates (sheet metal), 116
- 4-10 Heavy-duty shears, 117
- 4-11 Band saw for sheet metal cutting, 117
- 4-12 Burning torch, 118
- 4-13 Profile cutter, 120
- 4-14 Flame planer, 120
- 4-15(a) Rolls used for shell plate curving, 120
- 4-15(b) Rolls used for forming round components, 120
- 4-16 Press used for bending plate, 121
- 4-17 Press brake, 121
- 4-18 Gap press, 121
- 4-19 Frame bender, 122
- 4-20 Curvature from line heating, 122
- 4-21 Local reactions from line heating, 122
- 4-22 Convergent type torch tip, 123
- 4-23 Typical line heating operations, 124
- 4-24 Butt weld, 125
- 4-25 Fillet weld, 125
- 4-26 Metallurgical zones in welding, 125
- 4-27 Typical penetrations for various welding processes, 125
- 4-28 Single and multi-pass welds, 125
- 4-29 Gas welding process, 128
- 4-30 Oxyacetylene gas welding equipment, 128
- 4-31 Electric arc welding processes, 129
- 4-32 Manual shielded metal arc welding, 130
- 4-33 Manual shielded metal arc welding process, 130
- 4-34 Manual shielded metal arc welding positions, 130
- 4-35 Gravity welding machine, 131

- 4-36. Automatic shielded metal arc welding, 131
- 4-37. Submerged arc welding, 131
- 4-38(a). Submerged arc welding, semiautomatic, 132
- 4-38(b). Submerged arc welding, automatic equipment, 132
- 4-39. Stud welding, 132
- 4-40. Gas tungsten arc welding, 133
- 4-41. Gas metal arc welding, 133
- 4-42. Plasma metal inert gas welding, 134
- 4-43. Electroslag welding, 134
- 4-44. Electrode gas welding, 134
- 4-45. Classification of fairing methods, 135
- 4-46. Distortion removal following stiffener welding, 136
- 4-47. Distortion removal, 137
- 4-48. Shipyard machine shop, 138
- 4-49. Pipe shop band saw, 139
- 4-50. Plasma arc pipe cutter, 139
- 4-51. Pipe bending machine with numerical control, 140
- 4-52. Palletized pipe pieces, 141
- 4-53. Sheet metal duct work, 141
- 4-54. Sheet metal cutter with numerical control, 141
- 4-55. Press brake for sheet metal cutting and forming, 141
- 4-56. Turret press, 142
- 4-57. Conveyor used at surface preparation and coating work station, 144
- 4-58. Roller and chain conveyor in a sub-assembly line, 144
- 4-59. Conveyor in a pipe shop, 144
- 4-60. Top-running bridge crane, 145
- 4-61. Under-running bridge crane, 145
- 4-62. Magnetic clamp for crane steel handling, 145
- 4-63. Gantry crane, 145
- 4-64. Jib crane, 146
- 4-65. Hammerhead crane, 146
- 4-66. Mobile crane, 146
- 4-67. Block and tackle, 146
- 4-68. Flatbed truck moving a boiler, 147
- 4-69. Forklift truck, 147
- 4-70. Heavy-lift crawler vehicle, 147
- 4-71. Pallets, 148
- 4-72. Riggers installing a rudder, 149
- 4-73. Staging, 149
- 4-74. Mill scale layer composition, 152
- 4-75. Blast cleaning facility, 153
- 4-76. Hull bottom cleaner, 153
- 4-77. Self-propelled deck cleaning unit, 154
- 4-78. Portable pressure blaster, 154
- 4-79. Push mower type vacuum blaster, 154
- 4-80. Centrifugal flagellator, 155
- 4-81. New construction painting process, 157
- 4-82. Painting facility, 158
- 4-83. Piping unit hydrostatic test before erection, 159
- 5-1. Production organization properties, 162
- 5-2. First-generation shipyard layout, 163
- 5-3. Second-generation shipyard layout, 164
- 5-4. High-capacity, in-line process shipyard, 165
- 5-5. In-line process shipyard in full production, 165
- 5-6. Self-propelled transporter, 165
- 5-7. Third-generation shipyard layout, 167
- 5-8. Fourth-generation shipyard layout, 169
- 5-9. Proposed fourth-generation newbuilding yard layout, 170
- 5-10. Longitudinal-sloped building ways, 171
- 5-11. Graving dock, 172
- 5-12. Side-launch ways, 173
- 5-13. Floating dry dock with removable wing wall, 173
- 5-14. Floating dry dock with heavy-lift translation system, 173
- 5-15. Synchrolift, 174
- 5-16. Level building launch facilities, 174
- 5-17. Warehouse facility, 175
- 5-18. Flow diagram of N/C steel marking process, 176
- 5-19. Typical layout of a steel curved panel shop and panel line, 178
- 5-20. Automatic stiffener welding, 179
- 5-21(a). Large shipyard steel panel line in operation, 179
- 5-21(b). Larger shipyard steel panel line schematic, 179
- 5-22(a). Shipyard steel panel line schematic, 179
- 5-22(b). Shipyard steel panel line in operation, 180
- 5-23. Panel line blast and coat facility, 180
- 5-24. Typical layout of a block surface preparation and coating facility, 181
- 5-25. Erection site painting, 181
- 5-26. Schematic of a semiautomated pipe shop, 182
- 5-27. Pipe storage and retrieval rack, 182
- 5-28. Pin jig, 183
- 5-29. Typical shipbuilding jigs and fixtures, 184-87
- 5-30. Adjustable mobile scaffolding, 188
- 5-31. Erection work unit, 188
- 5-32. Process lane facility layout, 190
- 5-33. Platen/block categories, 191
- 5-34. Flat block platen, 192

- 6-1. Product-oriented design process, 196
- 6-2. The pallet concept, 198
- 6-3. Information interchange to integrate HBCM, ZOFM, and ZPTM, 199
- 6-4. Intensity of group technology engineering effort, 201
- 6-5(a). The design and engineering cycle, marketing to contract, 202
- 6-5(b). The design and engineering cycle, contract to Go meeting, 203
- 6-5(c). The design and engineering cycle, Go meeting to K meeting, 203
- 6-5(d). The design and engineering cycle, K meeting to ML meeting, 204
- 6-5(e). The design and engineering cycle, ML meeting to keel laying, 204
- 6-6. Preliminary block plan, 205
- 6-7. Functional design responsibilities, 206
- 6-8. Structural key plan, 208
- 6-9. Structural key plan, 208
- 6-10. Structural key plan, 209
- 6-11. Structural key plan, 209
- 6-12. Diagrammatic of part of a seawater ballast system, 210
- 6-13. System plan for part of forecastle deck mooring system, 211
- 6-14. Material ordering zones, 212
- 6-15. Material list by system (MLS), 212
- 6-16. Transition design responsibilities, 214
- 6-17. Composite draft of an engine room, 215
- 6-18. Separation of types of outfitting materials on composite arrangements, 217
- 6-19. Composite arrangements showing hull outfit, 218
- 6-20. Work instruction design responsibilities, 219
- 6-21. Coordination of design and material definition, 220
- 6-22. Stages for outfitting components, 221
- 6-23. Mold loft-generated key plan, 223
- 6-24. Mold loft-generated yard plan, 223
- 6-25. Mold loft-generated work instruction, 224
- 6-26. Mold loft-generated work instruction plan, 224
- 6-27. Mold loft-generated material list, 225
- 6-28. Mold loft-generated material list for a pallet, 226
- 6-29. Mold loft-generated schedule, 226
- 6-30. Information booklet title page, 227
- 6-31. Improved design approach, 228
- 6-32. Design and production information useful for improving design at various stages, 229
- 6-33. Classification of standards, 230
- 6-34. Standard structural assembly detail, 230
- 6-35. Standard machinery arrangement module, 231
- 6-36. Standard piping layout module, 231
- 6-37. Standard outfit unit module, 231
- 6-38. Use of geographical arrangement of material, 233
- 6-39. Pipe passages reserved for multiple pipe runs, 234
- 6-40. Pipe passages reserved for multiple pipe runs, 234
- 6-41. Pipe runs parallel to XYZ axes, 235
- 6-42. Common supports for pipe, 235
- 6-43. Pipe supported on common edges, 235
- 6-44. Components aligned side by side, 236
- 6-45. Outfit units include pipe pieces for other systems, 236
- 6-46. Small independent tanks built as outfit components, 237
- 6-47. Block joints avoid interference with components, 237
- 6-48. Blocks are designed to be stable right side up and upside down, 238
- 6-49. Shelf plates facilitate pipe penetration installation, 238
- 6-50. Logic for overlapping design stages, 239
- 6-51. Standard format for purchase order specifications, 241
- 6-52. Preventatives and countermeasures for design changes, 243
- 6-53. An integrated CAD/CAM system, 245
- 6-54. CAD-generated key plan, 247
- 6-55. CAD-generated work instruction, 248
- 6-56. CAD-generated schedule review, 249
- 6-57. CAD/CAM future, 249
- 6-58. CAD/CAM network, 250
- 7-1. The management cycle, 253
- 7-2. Build strategy process, 254
- 7-3. Build strategy process flow, 255
- 7-4. Network example, 256
- 7-5. Productivity indices, 258
- 7-6. Different levels of detail in planning, 259
- 7-7. Interrupted work flow, 260
- 7-8. Level work flow, 260
- 7-9. Scheduling objectives for design and material definition, 262
- 7-10. Shipbuilding master schedule, 262
- 7-11. Design scheduling sequence, 263
- 7-12. Design department master schedule, 264
- 7-13. Ship design master schedule, 265
- 7-14. Ship design group schedule, 266
- 7-15. Drawing issue schedule, 267
- 7-16. Design personnel schedule, 268
- 7-17. Man-hour control curve, 269

- 7-18. Scheduling hierarchy, 271
- 7-19. Milestone schedule, 272
- 7-20. Outfitting master schedule, 272
- 7-21. Monthly schedule, 273
- 7-22. Weekly schedule, 273
- 7-23. Planning and scheduling cycle, 274
- 7-24. Shop organization by zone/problem area/stage, 276
- 7-25. Communication and feedback channels, 277
- 7-26. Typical work unit, 282
- 7-27. L-type grand blocks, 284
- 7-28. Block definition consistent with integrated HBCN, ZOFGM, and ZPTM, 285
- 7-29. Hull construction production planning flow, 286
- 7-30. Hull construction production scheduling flow, 287
- 7-31. Man-hour budget determination system, 293
- 7-32. Manpower expenditures for hull construction, 299
- 7-33. Manpower expenditures for machinery outfitting, 299
- 7-34. Manpower expenditures for electrical assembly (noncable), 299
- 7-35. Manpower expenditures for electric cable assembly, 299
- 7-36. Production progress for hull construction, 299
- 7-37. Typical cost centers, 300
- 7-38. Productivity of parts fabrication, 301
- 7-39. Productivity of subassembly and block assembly, 301
- 7-40. Productivity of erection, 301
- 7-41. Productivity of machinery outfitting, 301
- 7-42. Productivity of electrical assembly (noncable), 301
- 7-43. Productivity control group, 303
- 7-44. Relationship of material to design, procurement, and production, 304
- 7-45. Flow of material-related information in design, 306
- 7-46. Critical path model of material lead time, 307
- 7-47. Material control classifications, 307
- 7-48. Material control identification codes, 309
- 7-49. Structure for material cost classification, 310
- 7-50. Functional flow of the requisition process, 311
- 7-51. Typical classification standards, 313
- 7-52. Relationship of material lists to design and procurement, 314
- 7-53. Typical breakdown of work to pallets, 315
- 7-54. Functional flow of warehousing and palletizing processes, 316
- 7-55(a). Pallets stored outdoors, 317
- 7-55(b). Pallets stored outdoors, 317
- 7-56. Subcontractor deliveries treated like pallets, 317
- 7-57. Palletizing flow for material issue, 317
- 8-1. Normal distribution of variation from design dimension of cut flat bars, 320
- 8-2. Normal distribution of longitudinal spacing, 321
- 8-3. $\bar{x}$ and R control charts for variation of dimensions of N/C burned parts, 321
- 8-4. Normal distribution of random samples taken from a normal population, 322
- 8-5. Random sample data to be entered on an $\bar{x}$ and R control chart, 322
- 8-6. Merged variation of fitting flat bar between longitudinals, 323
- 8-7. Relationship of standard ranges and tolerance limits, 325
- 8-8. Erection joint gap rework types, 325
- 8-9. Accuracy control cycle, 327
- 8-10. Accuracy control planning process, 328
- 8-11. Sources of variation by stage of construction, 329
- 8-12. Stages at which accuracy control measurements are taken, 330
- 8-13. Vital points and dimensions, 331
- 8-14. Variation merging equation example, 332-33
- 8-15. Relationships among accuracy standards and stages of construction, 336
- 8-16. Accuracy control check sheet, 338
- 8-17. Sight line templates for checking curved plate accuracy, 339
- 8-18. Vital dimensions on a flat block which incorporates some curved shell, 339
- 8-19. Accuracy control measurements during erection, 340
- 8-20. Accuracy control information flows, 341
- 8-21. Analysis of rework at block weldings, 343
- 8-22. Normal distribution of erection joint gap, 343
- 8-23. Shifting an erection joint gap distribution to control the type of rework required, 344
- 8-24. Hull erection rework analysis and report, 344-47
- 8-25. Histograms of variations of different characteristics, 348
- 8-26. Regular control items, 350
- 8-27. Position dimension diagram, 351

- | | | | |
|-------|--|-------|--|
| 8-28. | Block overall dimension report to be used to plan erections, 352 | 9-10. | Classification by product, 375 |
| 8-29. | Longitudinal end position report to be used in plan erection, 352 | 9-11. | Aggregate schedule for a zone-oriented conversion, 376-77 |
| 8-30. | Mold loft error list and frequency chart, 354 | 9-12. | Work package identification sheet, 378 |
| 8-31. | Weld shrinkage analysis based on work sequences, 355 | 9-13. | Composite drawing, 379 |
| 8-32. | Alternative assembly sequences, 356 | 9-14. | Functional zone representation, 380 |
| 8-33. | Excess distribution must be determined for each alternative assembly sequence, 357 | 9-15. | Geographic zone representation, 380 |
| | | 9-16. | Variable zone representation, 381 |
| | | 9-17. | Using AIM, 383 |
| 9-1. | Maintenance/repair life of a ship, 360 | 9-18. | Unscheduled voyage repairs, 387 |
| 9-2. | Breakdown of U S ship repair market, 361 | 9-19. | Example of bottom damage, 388 |
| 9-3. | Nature of the industry, 361 | 9-20. | Example of bottom damage, 389 |
| 9-4. | U S Navy shipbuilding and repair budgets, 364 | 9-21. | Planned maintenance, 392 |
| 9-5. | Approach selection criteria, 367 | 9-22. | Rigging needed to remove a bull gear from the main reduction gear during a repair cycle, 393 |
| 9-6. | Representative layout for a small repair yard, 369 | 9-23. | Overhauls, 395 |
| 9-7. | Representative layout for a larger repair/conversion shipyard, 370 | 9-24. | Conversion of an older tanker for continued use, 397 |
| 9-8. | Systems-oriented planning network for repair, 372 | 9-25. | The conversion/modernization decision, 397 |
| 9-9. | Stages, 374 | 9-26. | World merchant fleet age distribution, 399 |
| | | 9-27. | Conversion and modernization, 400 |
| | | 9-28. | Initial zone breakdown, 402 |
| | | 9-29. | Analysis of vessels broken up in 1992, 405 |

Tables

- | | | | |
|------|--|------|---|
| 1-1. | The world's leading shipbuilding nations, 17 | 4-7. | Factors present in the marine environment that cause corrosion, 151 |
| 1-2. | U S shipyard new construction and repair facilities, 19 | 4-8. | Relative location of metals in the electro-motive series, 151 |
| 1-3. | Hourly compensation for shipyard workers worldwide (U S \$), 21 | | |
| 4-1. | Requirements for ordinary-strength hull structural steel, 113 | 5-1. | Sample percentage of covered area by production stage for a product-oriented shipyard, 175 |
| 4-2. | Requirements for higher-strength hull structural steel, 114 | 5-2. | Recommended cutting methods for steel parts, 177 |
| 4-3. | Properties of high-strength hull structural steels developed for Navy ship construction, 115 | 6-1. | Comparison of intensity of engineering effort for a large commercial vessel construction project, 200 |
| 4-4. | Applicability of cutting processes to materials, 118 | | |
| 4-5. | Characteristics of fusion welding processes, 127 | 7-1. | Example of data required to develop a network, 256 |
| 4-6. | Weapons systems components of combatant ships, 143 | | |

PREFACE

In 1981 the leaders of the National Shipbuilding Research Program (NSRP) recognized the need for greater focus on shipbuilding education; the result was the establishment of an education panel (SP-9) within the Society of Naval Architects and Marine Engineers Ship Production Committee—the implementation arm of the NSRP. The first project authorized by the panel was a textbook on advanced concepts of ship production. The first edition of the book was published in 1988. In 1993 the decision was made to revise the book, and to update its contents to be consistent with the technology changes that have occurred in the years since the first edition was released. This book is the revised, second edition.

Significant changes have been made in the second, revised edition from the text found in the original version. Chapter I, which contains the history of shipbuilding and statistics relating to production and market share, has been updated to have more current information. Chapter II has been expanded to more directly incorporate into the text material relating to shipbuilding economic theory. In Chapter IV there has been new material added that relates especially to fabrication processes. Throughout this section there has been an updating of all process information to more accurately reflect the state of technology that currently exists. Antiquated information has been removed from Chapter V

(Shipyard Layout) and new material has been inserted that more accurately reflects the conditions of current ship production facilities. Chapters VI (Ship Design and Engineering), VII (Planning, Scheduling, and Production Control), and VIII (Accuracy Control) have all been updated to reflect the impact of the computer on all of these important areas. Finally, Chapter IX (Ship Conversion, Overhaul, and Repair) has been totally rewritten; this chapter now reflects the experiences of a major consulting firm that has extensively supported shipyards in the improvement of their conversion and repair operations.

Importantly, the illustrations and tables have been completely reorganized and improved throughout the second edition. It is this feature that will be the most quickly recognized in a comparison of the two editions.

The authors of the first edition were Professor Richard Lee Storch, University of Washington; Dr. Colin P. Hammon, consultant; and Professor Howard M. Bunch, University of Michigan. A fourth author, Richard C. Moore, University of Michigan, was added to support the preparation of the second edition, especially in the revision of Chapter IX.

Appreciation continues to be expressed to those who were heavily involved in the preparation of the first edition, and whose effort is still recognizable in the second edition: Mr. Robert Baseler, Mr. William Blaiklock, Mr. C.P. Buckley, Mr. Robert Slaughter, Dr. Wil-

liam Zeigler, Mr. John Peart, Mr. Raymond Ramsey, Mr. Paul Vickers, and Mr. George O'Keefe. Additional contributors who supported preparation of the second edition were Mr. Douglas Peel; Mr. Robert E. Luby, Jr.; and Mr. William J. Swahl; all were involved in the revision of Chapter IX. New photographs seen in the second edition have been supplied by Ingalls Shipbuilding (Mr. Jesse Brasher), Avondale Shipyards (Mr. Steven Maguire), and Newport News Shipbuilding (Mr. Robert P. Leber).

A special expression of indebtedness is reaffirmed to Mr. L.D. Chirillo. His manuscripts, including "Outfit Planning," "Product Work Breakdown Structure," "Integrated Hull Construction, Outfitting, and Painting,"

"Process Analysis via Accuracy Control," "Design for Zone Outfitting," and "Line Heating" were used extensively in the first edition, and have been carried over into the second. The logic developed in those works permeates the text in both editions.

A final expression of gratitude is extended to Ms. Pamela Cohen, research associate, University of Michigan Transportation Research Institute. Her patience and forbearing in dealing with the authors was truly remarkable.

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SHIP PRODUCTION

INTRODUCTION

1. The Shipbuilding Process

Shipbuilding is an industry that produces products (ships, offshore structures, floating plants, etc.) for customers (private owners, companies, governments, etc.). In most cases, the product is built to order and customized to the specific requirements of the purchaser. This applies even in cases where a similar series of ships is being built. The entire process is likely to vary somewhat, depending on the customer involved, but it generally involves a number of specific stages. These may be summarized as:

- development of owner's requirements
- preliminary/concept design
- contract design
- bidding/contracting
- detail design and planning
- construction

The first stage in the shipbuilding process is the formulation of the product requirements by the customer. For example, a shipping line may forecast the need for a means of transporting 250,000 automobiles per year between Japan and California; a state transportation agency may need to ferry 150,000 passengers per day across an inland waterway over 10 routes averaging 30 trips per route; an oil company may need to transport 10 million tons of crude oil per year from the Caribbean to the northeast United

States; or the U.S. Navy may need a ship capable of delivering supplies to support a battle group anywhere in the world on short notice. Alternatively, a shipping line owner may forecast an increase in container trade between the United States and the People's Republic of China of an unspecified nature and amount. The definition of the use or mission of a new ship may be narrow or broad, but the end product should reflect the owner's needs and intended use.

Once an owner has identified the need for a new ship and defined operational requirements, the next stage involves preliminary definition of the basic characteristics of the vessel. This preliminary or concept design stage can be done internally by the owner's staff, by a design agent hired by the owner, or by the staffs of one or more shipyards. Common practice in the United States (but not overseas) has been to use a design agent for preliminary design. A notable exception is the U.S. Navy, which has a large internal preliminary design section. Owners with considerable experience with particular ship types may, in order to satisfy specific operational requirements, approach a shipyard directly. The aim is to develop a design that will meet the requirements while taking advantage of the building experience and capability of a particular shipyard to minimize con-

struction time and cost. The end product of this stage is a general definition of the ship, including dimensions, hull form, general arrangement, powering, machinery arrangement, mission systems definition (such as cargo capacity and handling equipment, combat systems, or habitability), capacities of variable weights (such as fuel oil, water, crew, and stores) and preliminary definition of major systems (such as structural, piping, electrical, machinery, and ventilation [HVAC]).

Based on the general description of the ship to be built, as determined by the end product of the preliminary design stage, more detailed information is required to permit bids and/or contracts to be prepared. This information, called the contract design, must be of sufficient detail to permit the preparation of cost and time-to-build estimates by shipyards interested in the shipbuilding project. As in the preliminary design stage, this work can be performed by the owner's staff, by design agents, or by shipyard personnel. Preparation of contract design packages by the owner's staff is uncommon.

Following completion of the contract design stage, a specific shipyard is chosen to build the vessel. Unless an owner has involved a shipyard in the preliminary and/or contract design stage and thus is negotiating a contract based on a mutually agreeable design, competitive bidding based on the contract design and specifications is common practice. Due to the high cost of a new ship, contracts are generally very long and complex. The most significant factors are cost, delivery date, and performance requirements.

After the bidding process is complete and a contract has been signed, the fifth stage of the shipbuilding process, detail design and planning and scheduling, proceeds. Shipbuilding involves the purchasing of tons of raw materials and many thousands of components, the manufacturing of thousands of parts from the raw materials, and the assembly of these parts and components. Therefore,

complex and very detailed planning is required. Detail design and planning must answer the questions of "what, where, how, when, and by whom." Determining *what* parts, assemblies, and systems are to be built and what components are to be purchased is primarily detail design. *Where* and *how* are facility-use questions that include determination of the location within the shipyard and construction tools and techniques to be used. Considerations of subcontracting and in-house manufacture versus purchasing are also answered here. These questions are resolved as part of planning. *When* determines the sequencing of all operations, including purchasing and manufacturing, as well as need times for information (design, planning, approvals, etc.). This is the scheduling function. Finally, *by whom* relates to the utilization of the shipyard work force. Clearly, there is considerable interdependence among the answers to these questions. The success of any shipyard or shipbuilding project is directly related to the answers to the questions or to the detail design and planning process.

The final stage of the shipbuilding process is the actual construction of the vessel. Ship construction can be considered to occur in four manufacturing levels. The first is parts manufacturing, using raw materials (such as steel plate and sections, pipe, sheet metal, and cable) to manufacture individual parts. The purchasing and handling of components can be considered to be a part of this lowest manufacturing level. The next manufacturing level involves the joining of parts and/or components to form subassemblies or units. These small collections of joined parts are then combined in the third manufacturing level to form hull blocks. Hull blocks are commonly the largest sections of ships built away from the final building site. Erection, the final manufacturing level, involves the landing and joining of blocks at the building site (such as launching ways, graving dock, or dry dock). The actual construction phase of

shipbuilding is primarily involved with assembly, whether of parts, subassemblies, or blocks, to form a completed vessel. An important part of the construction phase is verification that the ship complies with the contractual requirements. Consequently, the vessel is subjected to a series of tests and trials prior to delivery to the owner.

Shipbuilding can therefore be viewed as a process that begins when an owner perceives a need for a vessel to perform some set of functions, that proceeds through a number of stages of paperwork (design, contracting, planning, etc.), and that culminates in a massive collection and joining of parts and components to manufacture the desired vessel. Productive shipbuilding is highly dependent on careful consideration, control, and performance in each of these stages.

The shipbuilding industry is centuries old, paralleling the history of man. Shipbuilding techniques have changed in response to changes in vessel design, materials, markets, and construction methods. The organization of shipbuilding companies has also changed to match this progression.

Throughout its early history, shipbuilding, like most early industries, was craft oriented. As such, it was almost exclusively dependent on the skills of the craftsmen doing the work. Little planning was performed prior to beginning the construction. As owners became more specific in defining the desired characteristics of a new ship, shipbuilders were required to do more planning. Nevertheless, prior to the use of iron and steel for ships, little more than a scale model or a simple drawing of a proposed ship was used to guide construction.

As industrial processes became more complex and efficient, shipbuilders kept pace with changing technology. Shipbuilding began to be subdivided into specialties, such as hull construction, machinery, outfitting, and painting. More recently, the development of mass production techniques and welding

both had profound impacts on shipbuilding. As late as the 1960s and 1970s, shipbuilders continued to try to employ mass production or assembly line approaches. Since then, a different approach to shipbuilding has emerged and has proven to be better suited to the economic and technical condition of the industry. This approach is based on the application of group technology to shipbuilding. (Group technology is defined in Chapter II, Section 3.2.)

The goal of this textbook is to describe the principles and practices of shipbuilding employing group technology. As in any industry that has existed for many years, the system used is a mix of old and new techniques. The system described in this book is drawn from many sources, combining pieces of current practice from many places. Undoubtedly, no shipyard anywhere in the world operates precisely as is suggested herein. What is presented includes many parts that in combination produce a system aimed at optimizing productivity in shipbuilding under current economic and technological conditions. It is presented in a way that will provide the reader an opportunity to gain some knowledge of all aspects of the industry as it is currently evolving.

The book is organized to present a general overview and basic principles, followed by in-depth descriptions of individual pieces of the system. The remainder of Chapter I presents a series of basic definitions. A much more comprehensive glossary of terms is presented near the end of the book. Additionally a brief review of the status of the shipbuilding industry is presented. Chapter II deals with two major topics: first, an overview of the economic theory of shipbuilding and, second, the general principles of group technology. Chapter III is a detailed discussion of the application of group technology to shipbuilding, called product-oriented work breakdown structure. Chapter IV is a description of the metal manufacturing and construction pro-

cesses employed. Chapter V discusses the physical plant of a shipyard, indicating how the processes are combined and organized using group technology. Ship design and engineering, from the shipbuilder's perspective, are discussed in Chapter VI. Chapter VII then presents the planning, scheduling, and production control functions, including material control. Since these are of major importance to the overall productivity of the ship-

building system, this chapter provides a summation of the preceding material and is a focal point of the text. Chapter VIII describes the final critical piece of the system, accuracy control. Finally, Chapter IX discusses the importance of the ship conversion, overhaul, and repair aspects of the industry, and indicates the applicability of the system, as presented for new construction, to work on existing vessels.

2. Shipbuilding Terms and Definitions

Shipbuilding is the construction of ships, and a shipyard is the place where ships are built. Shipbuilding is a construction industry which uses a wide variety of manufactured components in addition to basic construction materials. The process therefore has many of the characteristics of both construction and manufacturing. Shipbuilding requires many workers having various skills (or trades), working within an established organizational structure at a specific location in which necessary facilities are available. The goal of a privately owned shipbuilding company is to earn a profit by building ships.

2.1 Ship Definitions

A ship, although a complex combination of things, can be most easily classified by its basic dimensions, its weight (displacement) and/or load-carrying capacity (deadweight), and its intended service. Figure 1-1 defines a number of basic ship dimensions as well as typical shipboard regions. Some specific definitions are dependent on the vessel type or service, but in general, most definitions are applicable for all ship types.

2.2 Ship Types

Ships can be subdivided into a number of classes based on their intended service. The primary classes are (1) dry cargo ships, (2)

tankers, (3) bulk carriers, (4) passenger ships, (5) fishing vessels, (6) industrial vessels, (7) combatant vessels, and (8) others (see Figure 1-2). No simple classification of ships by types is likely to be all-inclusive, but this general breakdown is sufficient to indicate general trends. Figure 1-3 shows typical in-board profiles of ships within each of these classes.[1]

2.3 Shipyard Facilities

A shipyard generally contains several specific facilities laid out to facilitate the flow of material and assemblies. There is no typical shipyard layout, partly because many shipyards were initially constructed in the nineteenth or early twentieth century. These yards have grown according to the availability of land and waterfront as well as in response to production requirements. Figure 1-4 is a representative layout. Typical important features are listed below:

- a location on land for erecting a ship, along with an associated means for getting the ship to the water, such as a graving dock, launching ways, or a floating dry dock
- piers for storing ships afloat to permit work to continue following launching
- shops for performing various kinds of work, such as

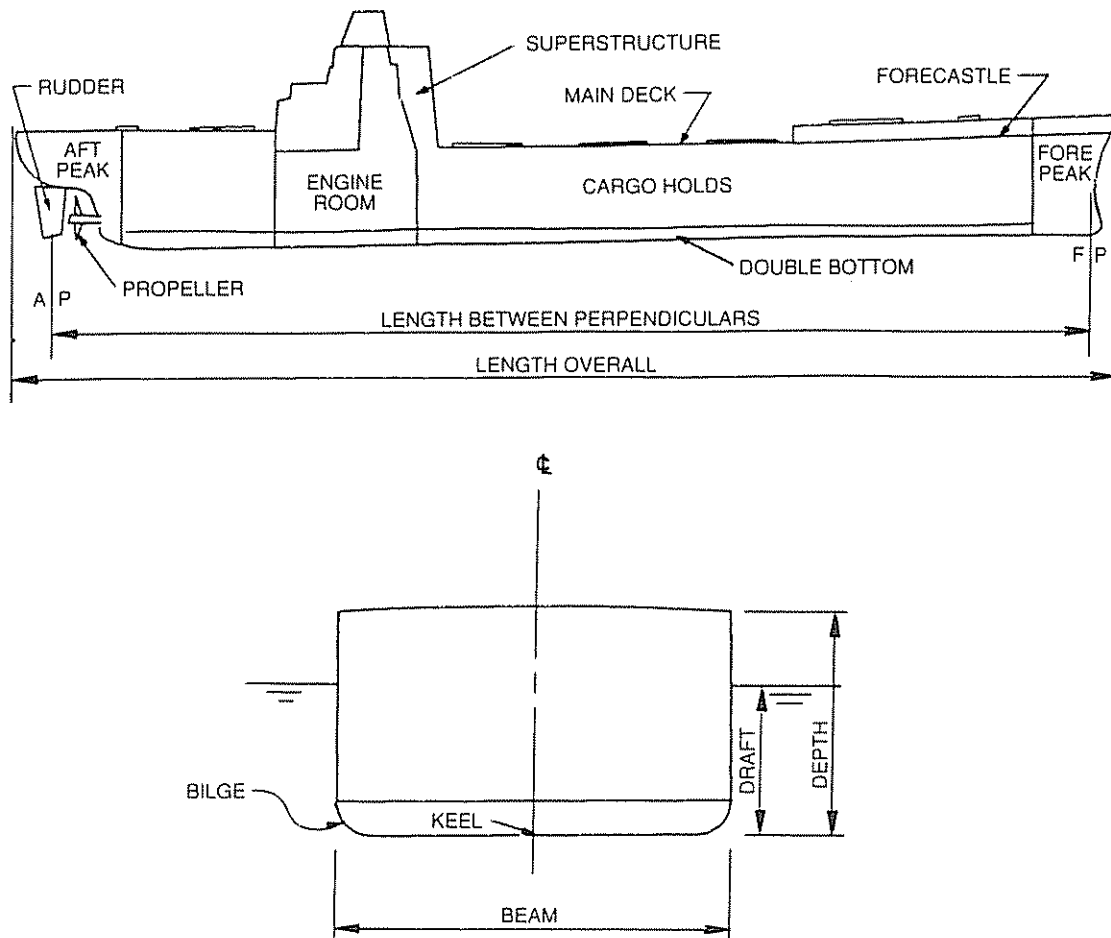


Fig. 1-1 Basic ship dimensions and definitions.

- steel marking, cutting, and forming shop
- steel assembly shop
- surface preparation and coating shop
- pipe shop
- sheet metal shop
- machine shop
- electrical shop
- storage, marshaling, and outdoor (blue sky) work areas
- offices and personnel support buildings (cafeteria, sick bay, etc.).

Associated with each of these general types of facilities are specific pieces of equipment that are related to the work carried out in that location. This subject will be discussed in detail in Chapters IV and V.

2.4. Organization

Shipyard workers are organized within departments or sections that are responsible for some aspect of the operation of the company. Although each company is likely to have some variation in its organization, the usual subdivision is into six functions. These are (1)

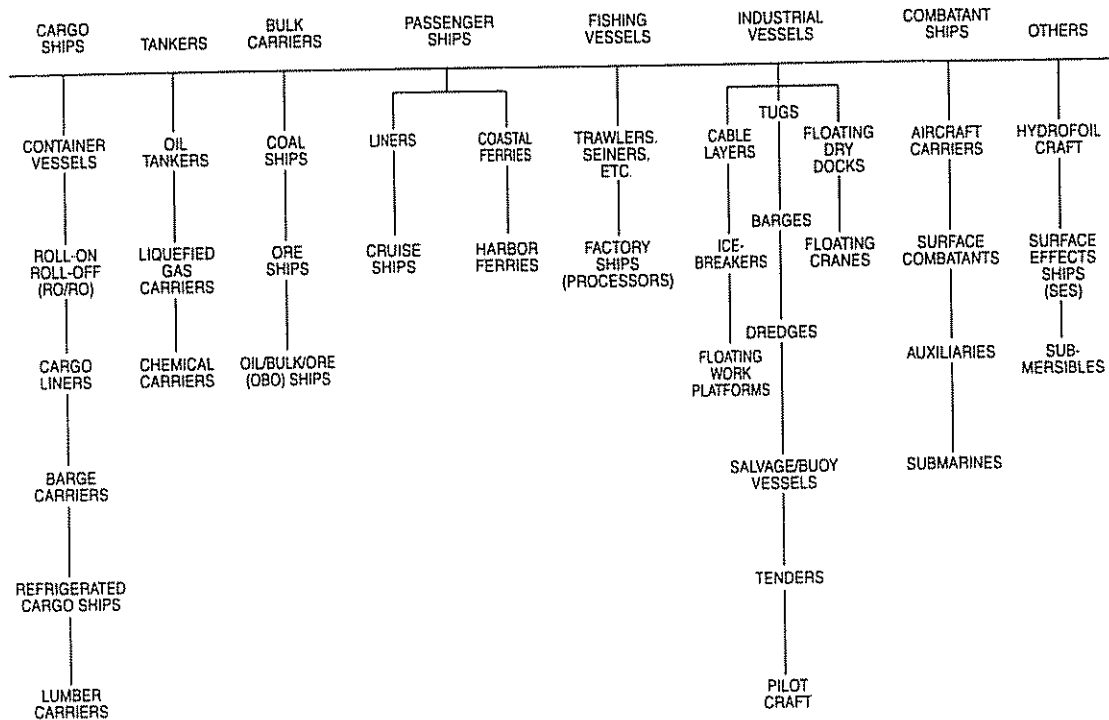


Fig 1-2. Ship types

administration, (2) production, (3) engineering, (4) purchasing, (5) quality assurance, and (6) project management (contract administration).

Administration includes the chief executive officer and staff, payroll, accounting, personnel, labor relations, safety, and job estimating.

Production is the department responsible for the actual construction. Consequently, all trades workers are in the production department. Planning, scheduling, and production control functions may also be in the production department. Generally, 75 to 85 percent of the shipyard's employees are in this department.

Engineering is responsible for the preparation of information about the construction project to be used by production in constructing the vessel. Engineering functions include preliminary design, detail design, production engineering, and, sometimes, bidding of new

jobs. Many shipyards subcontract some of the design work to outside design agents. Production engineering, which is playing an increasingly important role in shipbuilding, may in some cases occur in the production department, and it includes planning. The distribution of responsibilities between planning and production engineering varies widely, depending on the specifics of the shipyard organization.

The purchasing department is responsible for obtaining the materials to be used to build the ship. These include raw materials, subcontracted work, and components, and may also incorporate tools, transportation, manufacturing, and safety equipment.

Quality assurance is often a separate function within a shipyard that is responsible for documenting for the vessel owner, regulatory agency, and classification society that the vessel being constructed satisfies applicable rules, regulations, and contractual re-

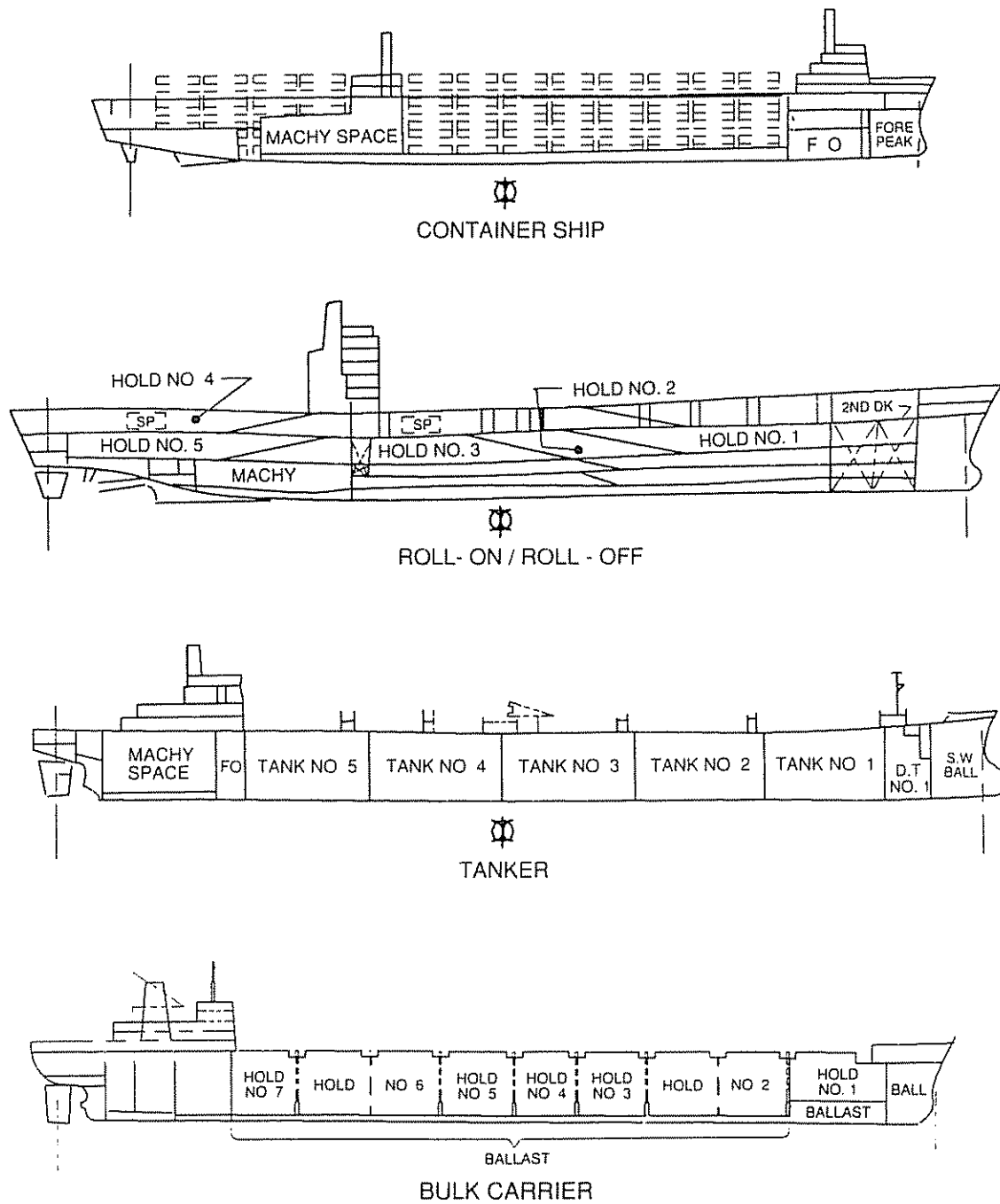
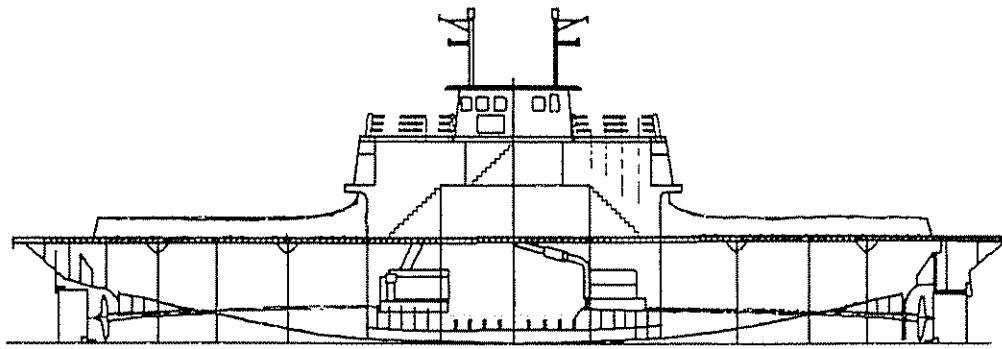
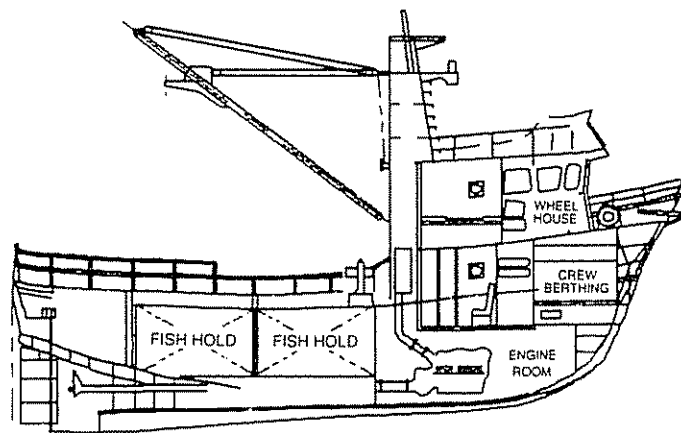


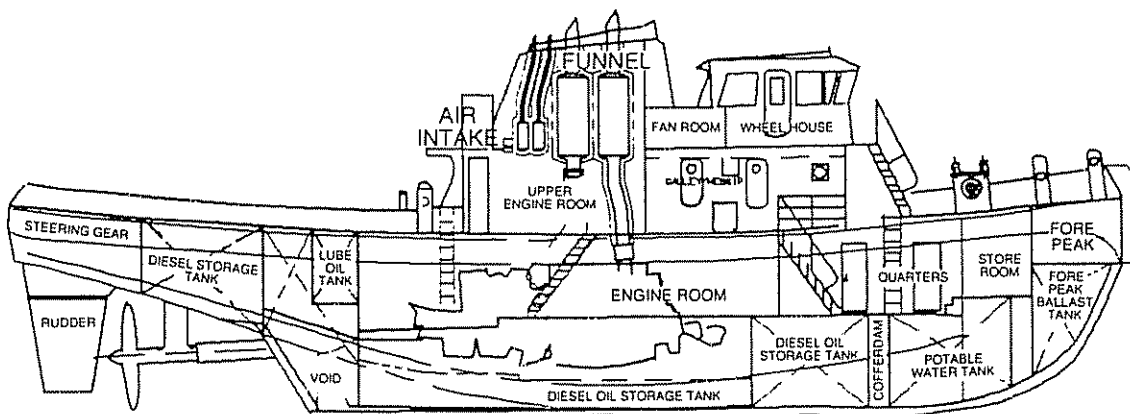
Fig. 1-3. Inboard profiles of major ship types



HARBOR FERRY



FISHING VESSEL



TUG

Fig. 1-3 (continued)

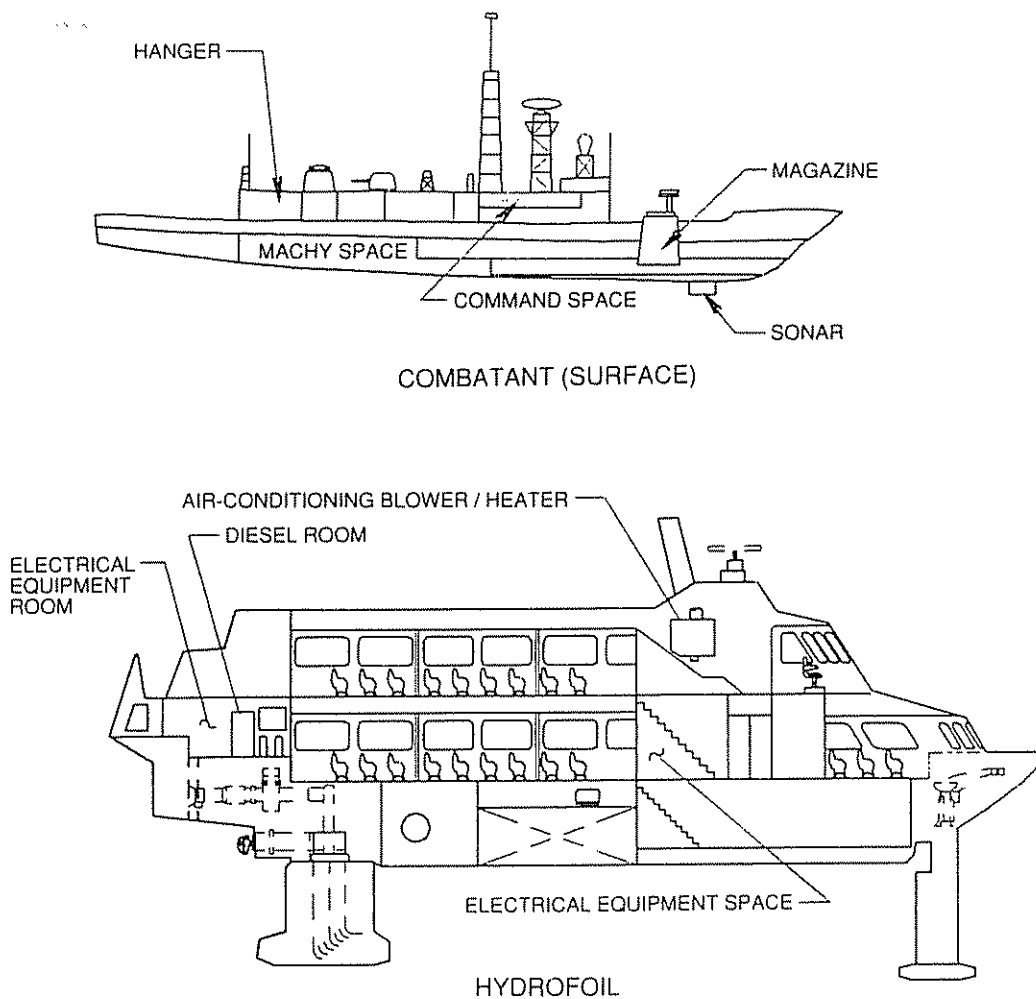


Fig 1-3 (continued)

quirements. A separate project management or contract management department is charged with overseeing the progress of a particular shipbuilding project. It monitors compliance with budgets, schedules, materials usage, and the overall progress of the shipbuilding program. Within this department, it is common to have shipbuilding superintendents who are responsible for each construction project. This department, too, has generally been the lead group in the implementation of statistical process control concepts into the yard's activities.

2.5 Trades

Within the production department, actual ship construction work is subdivided into various trade skills [2]. These are:

- air-conditioning equipment mechanic: installs, maintains, and repairs refrigeration and air-conditioning equipment
- blaster: prepares surfaces for coating by abrasive blasting (may be combined with painter)
- boilermaker: assembles boilers, tanks, and pressure vessels, using power tools

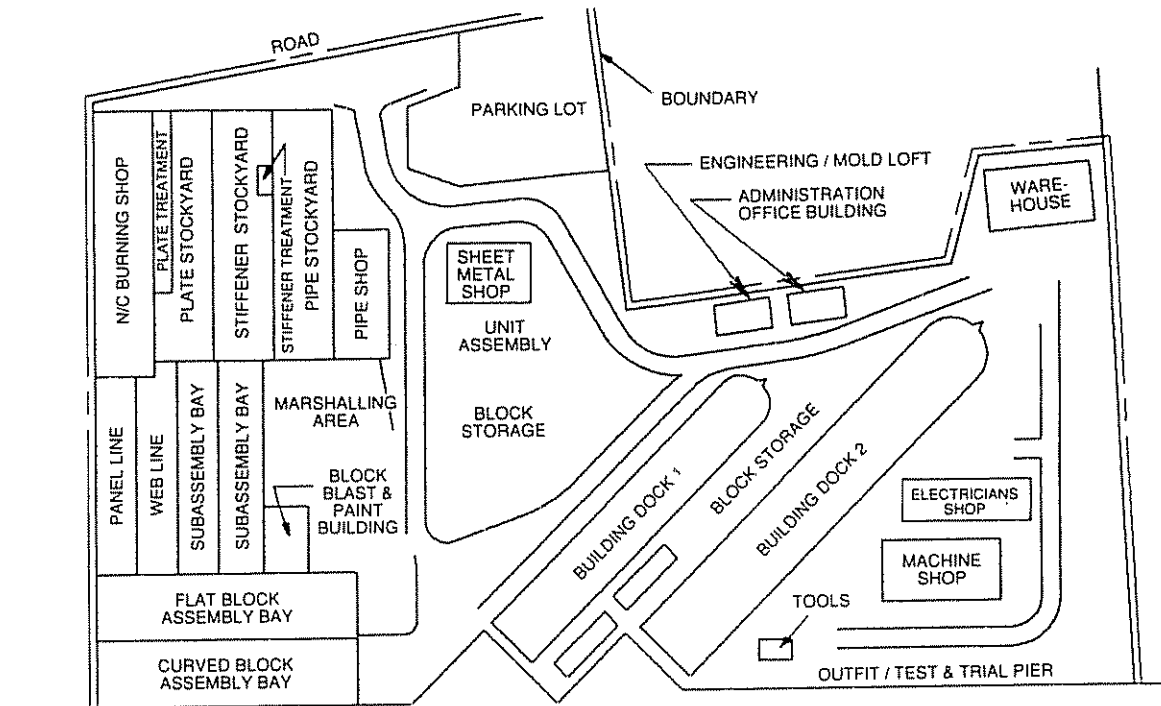


Fig. 1-4 Representative shipyard layout

and hand tools (may also refer to all of the steelworking trades)

- carpenter: fabricates and assembles wooden structures, gratings, keel blocks, and shorings, and is often responsible for launching (may also perform joinery work)
- chipper/grinder: grinds and chips weld splatter, high spots, burrs, weld slag, and rust from metal surfaces of ships to improve their appearance or prepare them for painting
- electrician (inside): installs and maintains wiring, fixtures, and equipment for shipyard facilities
- electrician (outside): installs and repairs wiring, fixtures, and equipment for all electrical services aboard ship
- electronics mechanic: works on various types of electronic equipment to put it in repaired operating condition
- electroplater: sets up, operates, and maintains metal plating baths to deposit metallic plating for protective purposes or decorative purposes, and to build up worn surfaces
- insulator: installs insulation in designated areas and on piping aboard ship
- joiner: installs finished panels, floor grouting, and tiling in shipboard living quarters
- laborer: performs a variety of shipyard tasks, such as carrying, digging, janitorial duties, etc.
- loftsmen: lays out lines of a ship to full scale on the mold loft floor and constructs templates and molds to be used as patterns and guides for layout and fabrication of various structural parts of ships (computer-assisted lofting, which has replaced full-scale layout, may be done by loftsmen or by engineers)
- machinist (inside): sets up and operates machine tools as well as fits or assembles parts to make or repair metal parts, tools, or machines

- machinist (outside): installs ship machinery such as propulsion machinery, auxiliary motors, pumps, ventilating equipment, and steering gear
- molder: heats and pours molten metal into hollow forms to produce all manner of metal parts (may also be called foundryman)
- ordnance equipment mechanic: repairs machinery and mechanical equipment such as cranes, pumps, motors, and conveyor systems associated with weapons systems
- painter: mixes and applies paint or other coating materials for protective and decorative purposes by means of spray gun, brush, roller, or immersion (may also perform surface preparation)
- patternmaker: plans, lays out, and performs machine operations and benchwork to construct, alter, and repair three-dimensional wood patterns and core boxes for use in making molds for foundry castings
- pipefitter: fabricates, lays out, installs, and maintains ship's piping systems such as steam heating, water, hydraulic, air pressure, and lubrication systems, using hand tools and shop machines (may also perform pipe welding)
- pipe welder: installs, repairs, and maintains shipboard piping systems by means of applicable welding processes
- rigger/crane operator: installs and repairs rigging and weight-handling gear, attaches hoists and handling gear to rigging, and operates cranes and other mobile material-handling equipment to lift, move, and position machinery, equipment, structural parts, and other heavy loads aboard ship (may also be called operating engineer)
- sheet metal mechanic: fabricates, assembles, installs, and repairs sheet metal
- shipfitter: lays out and fits up metal structural parts (such as plates, bulkheads, and frames) and maintains them in position for welding
- shipwright: constructs or repairs wooden ships or ship sections, sets and adjusts supports upon which a ship is built or docked, and aligns blocks that are to be joined to form a ship (may be combined with carpenter)
- tacker/burner: cuts steel plate by burning, washes welds, and applies temporary welds to position metals for final welding (may also be called boilermaker)
- welder: makes or repairs structures or parts, using gas or electric welding equipment, soldering equipment, gas or electric cutting equipment, etc. (may also be called boilermaker)

Work practices, work responsibilities, and trade divisions vary between shipyards. However, all actual construction work within a shipyard falls into the domain of trades such as those listed above.

2.6. Classification Societies and Regulatory Agencies

The principal maritime nations have established classification societies in order to improve vessel safety. Although the original purpose was to ascertain the relative risk of insuring specific vessels, classification societies now function more as safety regulatory bodies, and are often closely coordinated with a government regulatory agency. Classification societies generally publish rules for the design, construction, and maintenance of vessels. The U.S. society is the American Bureau of Shipping (ABS). Classification societies of other major shipping nations are:

- England—Lloyd's Register of Shipping
- France—Bureau Veritas
- Germany—Germanischer Lloyd

- Italy—Registro Italiano Navale
- Japan—Nippon Kaigi Ngokai
- Norway—Det Norske Veritas
- USSR—Register of Shipping of the USSR

Classification simplifies the structuring and determination of insurance rates. It also facilitates documentation and safety regulation by governments. An operator is not required to have a ship classified. If it is not, however, certain government agencies will have to be satisfied that the ship meets safety criteria before it can be documented and a safety construction certificate issued. An ABS representative will generally be on site for major commercial shipbuilding or conversion programs. Their purpose is to ensure that the vessel is built in accordance with the classifications for which the owner has applied. Items within their cognizance include the structural strength of the ship, the installation of certain equipment, such as anchors and hawsers, and reliability of machinery. (Mention should be made of ABS's approval of plans being required prior to production commencing. Proper understanding of ABS's plan approval requirements can help reduce this sometimes lengthy process.)

Ships are classified according to their intended uses, such as oil tanker, liquefied natural gas carrier, ore carrier, trawler, tug, etc. They are also classified according to operating environment. Special classes may apply to seagoing ships operating on restricted routes or for special purposes, and a

special class applies to ships, such as ferries, which operate only in sheltered waters (harbors, rivers, etc.). Special classes may be assigned because of unique design features. Oceangoing vessels may also be classified according to the level of ice strengthening. In order to maintain the initial classification, steel ships are usually surveyed annually. The condition of hull closure appliances, freeboard marks, and auxiliary steering gear is inspected. This is sometimes combined with the required docking survey. The ship is inspected in dry dock for corrosion, chafing, or distortion of the shell plating, stern frame, or rudder. Special surveys are also conducted at periodic intervals. This inspection varies with the age of the ship. In addition to regular periodic surveys, the societies require that damage repairs be accomplished according to society rules.

In addition to classification society inspection, government agencies inspect merchant vessels to assure that they are designed, built, and maintained according to published rules. Efforts have been made to avoid overlaps between classification society and regulatory body inspections. Primary areas of regulatory body safety involvement include stability, fire protection, machinery and electrical system safety, hazardous and polluting substance control, lifesaving equipment, and navigation and communication equipment. In the United States, merchant vessel safety inspection is carried out by the U.S. Coast Guard.

3. Status of the Shipbuilding Industry

Perhaps in no other industry (with the exception of shipping, to which shipbuilding is closely tied) are there as many diverse political factors that affect industrial organization and economic performance. The U.S. shipbuilding industry is now essentially a closed system, dependent on a single buyer, the federal government, for its existence. Operating

through the Navy and Maritime Administration (MarAd), the federal government has provided a market through direct purchase and differential subsidies. The government also provides a market indirectly through tax incentives, financing, and cabotage and cargo preference legislation. (Cabotage is the reservation of all domestic and

coastal trade to operators of U.S. built ships.) Political rather than economic considerations therefore provide the dominant stimuli that shape the structure and performance of the industry.

Industries such as construction are naturally isolated from direct world competition by the cost of transport, the nature of the product, and the production process. Some other manufacturers are naturally isolated from foreign competition by persistent buying habits and a high degree of product differentiation, as U.S. auto makers were prior to the 1970s. In such a climate, an industry may remain competitive even when production costs are high.

The market for ships is a worldwide market. Ship operators and builders freely cross national borders to obtain a price or technological advantage. In the absence of external factors, the shipbuilding industries of nations with a comparative advantage, based on resource markets, cheap labor, or superior technology, would be expected to prosper. The economies of nations that lack such an advantage would be expected to allocate resources to other activities. This simple economic model does not fit the realities of world shipbuilding. This is true primarily because most trading nations perceive the shipbuilding industrial base to be a vital national resource on other than strictly economic grounds. The national policy of most trading nations reflects a primary requirement to maintain some degree of control over the resources needed to move their products to foreign markets. They have therefore instituted policies aimed at assuring the existence of a nationally controlled fleet. In addition, some of these nations have supported their shipbuilding industries in order to provide the means of replacing the national fleet should it be threatened militarily or economically. Other nations have supported a shipbuilding industry as a "hub" industry for economic development. Many coastal nations also view a national

shipbuilding industry as essential for defense purposes.

3.1. The World Shipbuilding Market

Cycle swing is an important characteristic of the product market and one that has a predominant effect on industry structure. This is partly induced by national policy. The volume of U.S. Navy new construction and overhauls is determined by the political process, based on perceived national defense requirements. The market for merchant ships is similarly affected by national policy.

The market for U.S. ships operating in the U.S. intracoastal trade is affected by U.S. economic conditions generally. However, these effects are superimposed on the world market demand for ships. The U.S. economy tends to be generally synchronous with the world economy, and requirements for construction likewise follow the world economy and the world market for shipping.

The international market for merchant ships has historically been cyclical, with nine major cycles between 1890 and 1992 (see Figure 1-5). With the closing of the Suez Canal in 1959 and the oil embargo in 1973, the range of the peaks and troughs reached a new extreme. A cycle is also apparent in naval ship construction, involving delivery and decommissioning decisions. The first half of the 1970s were boom years for the world's shipbuilders. Between 1970 and 1975, the world fleet deadweight tonnage increased by 70 percent (gross tonnage of 58 percent). Much of this tonnage comprised supertankers built to carry crude oil from the Middle East to Europe and Japan. In 1973, the world order book was equivalent in deadweight tonnage to 50 percent of the world fleet.[3] Even U.S. shipbuilders, who have had a negligible share of the world market since 1959, received orders for 47 merchant ships in 1972, up from 13 in 1970.

After the Arab oil embargo in 1973, the entire world shipbuilding market contracted

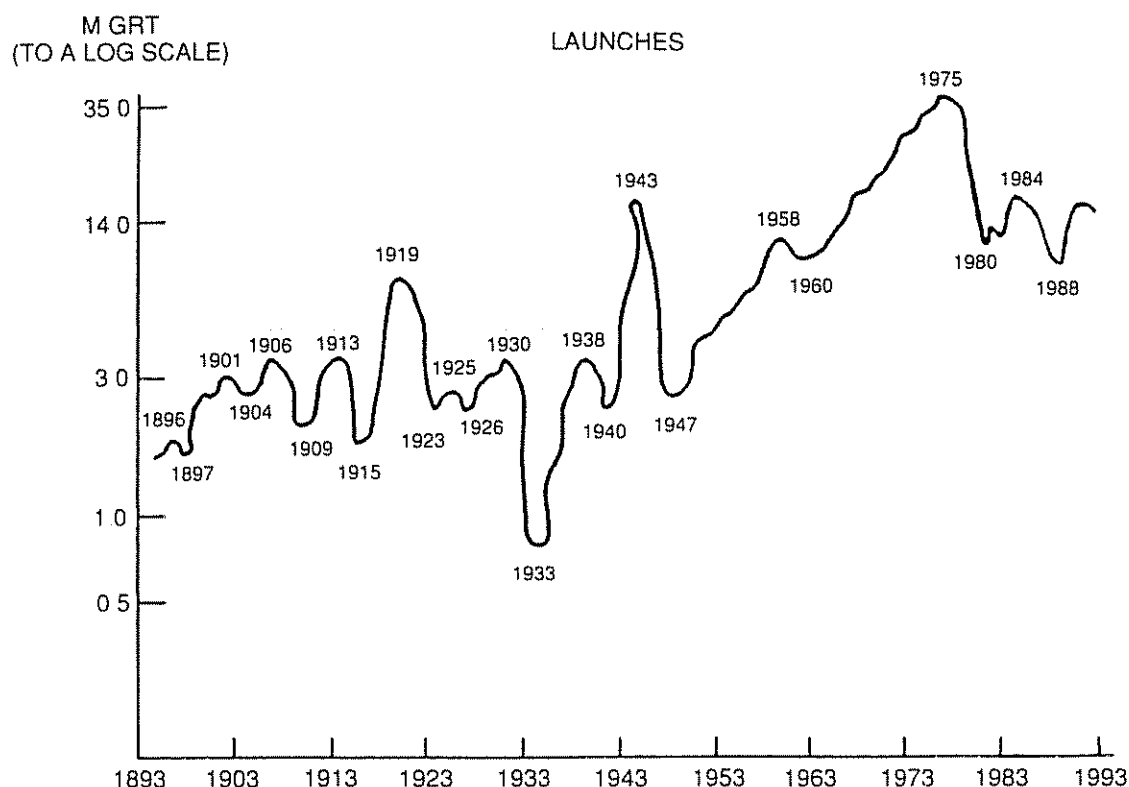


Fig. 1-5. World shipbuilding market cycles

dramatically. The worldwide order book declined from a peak of 242.3 million deadweight tons (dwt) in 1974 to 32.0 million in the first quarter of 1979, and some tankers were laid up as they were completed. Many of the marginal shipbuilders who were able to penetrate the market during the boom years went bankrupt or were nationalized. In particular, highly automated shipyards in Europe were either nationalized or restructured. Even Japan suffered many bankruptcies and a reduction in shipbuilding capacity of 35 percent.

Although some recovery occurred in the world shipbuilding market, its condition throughout the 1980s can be described as depressed. At the end of the decade, the industry was beginning to show signs of recovery, with modest increases occurring in the early 1990s.

The Association of Western European Shipbuilders estimated[4] that presently installed yard capacity for shipbuilding, worldwide, is about 18 million compensated gross tons. This translates into about 27 million dwt of new tonnage per year. New building requirements for the seven-year period 1993-2000 have been projected to be in the order of 330 million dwt, or about 47 million dwt per year, average.[5] The obvious conclusion is that during the remainder of the twentieth century, there will be pressure to expand world shipbuilding capacity.

As seen in Table 1-1 the bulk of the shipbuilding activities in recent years occurred in only a few countries. Twelve nations control over 90 percent of the market; the Far East yards have the lion's share, with Japan and South Korea in the lead. The composition of the leading nations has remained essentially

Table 1-1. The world's leading shipbuilding nations

(Ranking by percentage share in tonnage on order)

1985		1988		1992	
Japan	43.3%	South Korea	32.5%	Japan	39.0%
South Korea	19.0%	Japan	25.8%	South Korea	21.1%
Brazil	6.1%	Yugoslavia	5.0%	Denmark	5.4%
Taiwan	3.5%	Taiwan	3.9%	China	5.1%
China	3.4%	Brazil	3.5%	Taiwan	3.3%
Germany	2.1%	China	3.3%	Romania	2.9%
Poland	2.0%	Germany	3.2%	Brazil	2.7%
Spain	2.0%	Poland	3.1%	Germany	2.4%
Yugoslavia	1.9%	Spain	3.1%	Great Britain	2.4%
Romania	1.7%	Italy	2.7%	Poland	2.3%
Denmark	1.7%	Romania	2.3%	Spain	2.3%
U.S.A.	1.5%	Denmark	1.9%	Croatia	2.1%
All Others	11.8%	All Others	9.7%	All Others	9.0%

Total tonnage on order (Year-end records)

1985: 46,696,555 dwt	1988: 38,536,093 dwt	1992: 68,672,316 dwt
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Source: Fairplay "Newbuilding Supplement." Various issues. London

the same since 1980. Japan became the world leader in commercial shipbuilding in 1956 and has continued to maintain that position. South Korea, Spain, Taiwan, and Brazil emerged as strongly contending shipbuilding nations in the 1970s. In the early 1980s, the People's Republic of China also began a serious entry into the worldwide shipbuilding market.

To maintain their market share, the nations have followed a variety of marketing strategies, which have included subsidy schemes and major initiatives to improve productivity. Since 1975 the work forces have been reduced over 60 percent in West Europe, and over 70 percent in Japanese yards. These

reductions have been possible by increasing the amount of automation, standardization of designs, and rationalization of design, engineering, and production activities. During the 1990s, and possibly into the twenty-first century, it is expected that there will be changes in individual country shares. While the Far East yards are expected to maintain their dominance, it is expected that North European shipyards will reverse their long-term market share decline. There is also recent evidence that the East European yards will establish a market position, especially in the building of ships of relatively simple design. It is expected that China will also increase position, and the United States is putting

into place a major government-supported initiative to reestablish itself in the world commercial market.

3.2 The U.S. Shipbuilding Industry

As a major trading nation and world power, the United States has had a policy of maintaining a shipbuilding industrial base capable of expansion in time of war. This policy and the means of meeting national objectives have kept the industry alive, but not necessarily healthy. Although U.S. shipbuilders have been preeminent in the production of combatants, they have not been competitive in the world merchant ship market since the Second World War. Government-induced demand for merchant and navy ships has been highly cyclical, both from the viewpoint of the industry and individual shipbuilders. This has resulted in risk-aversion techniques such as labor intensiveness. The labor force can be reduced rapidly, whereas capital, once in place, represents a nearly constant cost regardless of the degree of utilization. Labor intensiveness is therefore efficient from the standpoint of the individual producer, but not necessarily efficient in terms of total national utilization of resources.

The shipbuilding industry is part of a political-economic system and responds to other elements within that system. Of particular importance to the objective of this text is the relation of technology to the other elements of the system. Past national policy has been directed at isolating the industry from the world market. This policy has, in many cases, resulted in a broad-based but low-technology and high-cost industry. In an effort to change this, several U.S. shipbuilders have embarked on a course of increasing productivity through improvements in management, using basically state-of-the-art technology. The success of this endeavor hinges in part on an understanding of the interactions among market, political, and technology factors.

The U.S. active shipbuilding base is defined as privately owned shipyards that are engaged in actively seeking construction contracts for naval and commercial ships over 1,000 tons. As of December 31, 1993, there were 39 shipyards (public and private) in the United States capable of building or drydocking a ship greater than 220 meters, and which had an active employment of more than 200 persons. The list is shown in Table 1-2. As seen, there are 14 new construction yards, 17 repair yards with dry dock facilities, and eight navy yards. Figure 1-6 displays the location of the yards.

Beyond the 39 shipyards shown in Figure 1-6 there are about 560 additional establishments in the U.S. Census's Standard Industrial Classification (SIC 3731 [Shipbuilding and Repairing]). According to the Department of Labor, aggregate employment in the private shipbuilding and repair sector in 1992 was 123,000 persons [6]. Additionally, the public shipyards also employed about 50,000-60,000, making the total U.S. shipyard employment figure slightly over 170,000—the largest number of shipyard workers in any nation outside China, and possibly Russia.

Approximately 80 percent of the total labor force of the primary active shipbuilding base consists of production workers. Employment levels have varied considerably over time for all but a few of these yards. Typically, about 80-90 percent of the total active shipbuilding base production workers are engaged in navy new construction, overhaul, repair, or conversion.

In U.S. shipyards, between 35 and 60 percent of the direct costs associated with building a ship are attributable to labor. In foreign yards the labor percentage is significantly less: 20-35 percent [7]. The major difference is related to the types of ships being built: the U.S. yards build naval ships primarily, and foreign yards concentrate on commercial ships. Also, some of the difference is

Table 1-2. U.S. shipyard new construction and repair facilities

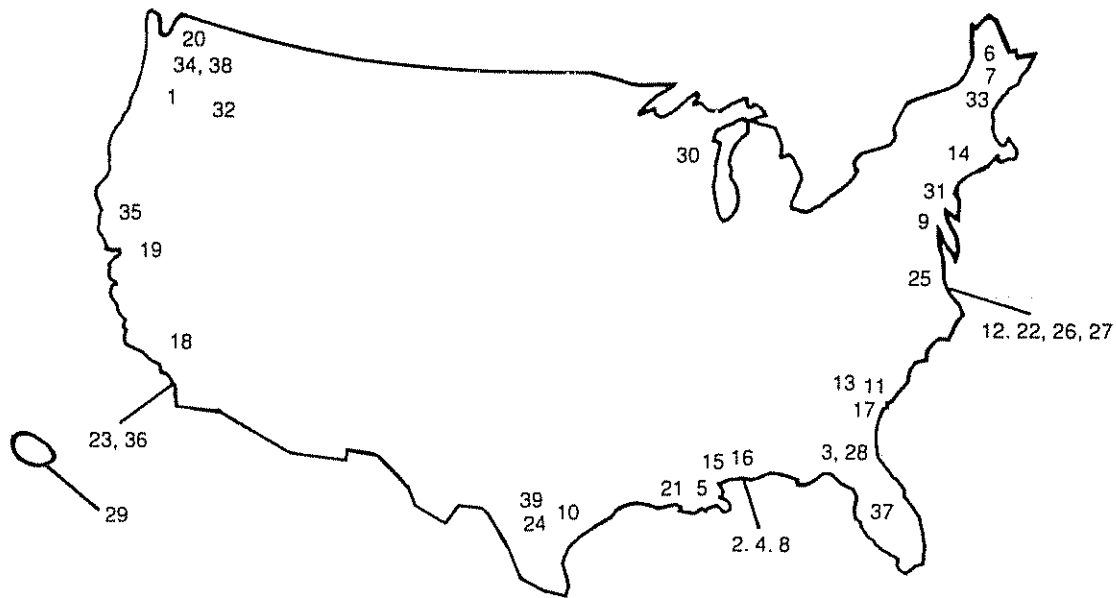
(Overall length >220m and more than 200 employees, October 1993)

YARD NAME	LOCATION	NEW CONSTRUCTION	REPAIR YARDS WITH DRY DOCK FACILITIES	U.S. NAVY YARDS
AK-WA Inc	Tacoma, WA		X	
Alabama Shipyard	Mobile, AL	X		
Atlantic Drydock Corp	Jacksonville, FL		X	
Atlantic Marine	Mobile, AL		X	
Avondale Industries	New Orleans, LA	X		
Bath Iron Works Corp	Bath, ME	X		
Bath Iron Works Corp	Portland, ME		X	
Bender Shipbuilding & Repair	Mobile, AL		X	
Bethlehem Steel Corp	Sparrows Point, MD	X		
Bethship Sabine Yard	Port Arthur, TX		X	
Charleston Naval Shipyard	Charleston, SC			X
Colonna's Shipyard	Norfolk, VA		X	
Detyens Shipyard	Mt Pleasant, SC		X	
General Dynamics	Groton, CT	X		
Halter Marine	Moss Point, MS	X		
Ingalls Shipbuilding	Pascagoula, MS	X		
Intermarine, USA	Savannah, GA	X		
Long Beach Naval Shipyard	Long Beach, CA			X
Mare Island Naval Shipyard	Mare Island, CA			X
Maritime Contractors	Bellingham, WA		X	
McDermott, Inc	Morgan City, LA		X	
Metro Machine Corp	Norfolk, VA		X	
Nat'l Steel & Shipbuilding Co	San Diego, CA	X		
Newpark Shipbuilding & Repair	Houston, TX		X	
Newport News Shipbuilding	Newport News, VA	X		
Norfolk Naval Shipyard	Portsmouth, VA			X
NORSHIPCO	Norfolk, VA		X	
North Florida Shipyards	Jacksonville, FL		X	
Pearl Harbor Naval Shipyard	Pearl Harbor, HI			X
Peterson Builders	Sturgeon Bay, WI	X		
Philadelphia Naval Shipyard	Philadelphia, PA			X
Portland Ship Repair Yard	Portland, OR		X	
Portsmouth Naval Shipyard	Kittery, ME			X
Puget Sound Naval Shipyard	Bremerton, WA			X
San Francisco Drydock	San Francisco, CA		X	
Southwest Marine	San Diego, CA		X	
Tampa Shipyards	Tampa, FL	X		
Todd Pacific Shipyards	Seattle, WA	X		
Trinity Marine Group	Beaumont, TX	X		
TOTAL COUNT		14	17	8

Adapted from "Report on Survey of U.S. Shipbuilding and Repair Facilities, 1993," Maritime Administration

related to productive efficiency. And cost of materials has an impact, as does the national wage rate.

In the 1940s, U.S. shipyards had the highest labor rates in the world. Fifty years later, however, the U.S. yards have signifi-



1 AK-WA Inc	Tacoma, WA	21 McDermott, Inc.	Morgan City, LA
2 Alabama Shipyard	Mobile, AL	22 Metro Machine Corp	Norfolk, VA
3 Atlantic Drydock Corp	Jacksonville, FL	23 Nat'l Steel & Shipbuilding Co	San Diego, CA
4 Atlantic Marine	Mobile, AL	24 Newpark Shipbuilding & Repair	Houston, TX
5 Avondale Industries	New Orleans, LA	25 Newport News Shipbuilding	Newport News, VA
6 Bath Iron Works Corp.	Bath, ME	26 Norfolk Naval Shipyard	Portsmouth, VA
7 Bath Iron Works Corp	Portland, ME	27 NOSHIPCO	Norfolk, VA
8 Bender Shipbuilding & Repair	Mobile, AL	28 North Florida Shipyards	Jacksonville, FL
9 Bethlehem Steel Corp	Sparrows Point, MD	29 Pearl Harbor Naval Shipyard	Pearl Harbor, HI
10 Bethship Sabine Yard	Port Arthur, TX	30 Peterson Builders	Sturgeon Bay, WI
11 Charleston Naval Shipyard	Charleston, SC	31 Philadelphia Naval Shipyard	Philadelphia, PA
12 Colonna's Shipyard	Norfolk, VA	32 Portland Ship Repair Yard	Portland, OR
13 Deytens Shipyard	Mt. Pleasant, SC	33 Portsmouth Naval Shipyard	Kittery, ME
14 General Dynamics	Groton, CT	34 Puget Sound Naval Shipyard	Bremerton, WA
15 Halter Marine	Moss Point, MS	35 San Francisco Drydock	San Francisco, CA
16 Ingalls Shipbuilding	Pascagoula, MS	36 Southwest Marine	San Diego, CA
17 Intermarine, USA	Savannah, GA	37 Tampa Shipyards	Tampa, FL
18 Long Beach Naval Shipyard	Long Beach, CA	38 Todd Pacific Shipyards	Seattle, WA
19 Mare Island Naval Shipyard	Mare Island, CA	39 Trinity Marine Group	Beaumont, TX
20 Maritime Contractors	Bellingham, WA		

Fig. 1-6 Locations of U.S. shipyards

cantly cheaper wage scales than almost all of the European yards, and are about the same level as those of Japan. Table 1-3 shows the hourly shipyard wage scales for the major shipbuilding nations for the period 1975-90, and shows the relative shift in U.S. position.

A part of the industry (about 200 yards) concentrates on ship repair. As mentioned,

only about 17 repair yards can accommodate vessels with a length in excess of 220 meters; about 55 more repair yards are capable of dry-docking vessels of in excess of 100 meters in length. Many smaller repair yards, called topside yards, have no dry-docking facilities at all. These yards perform above-water ship and barge repair, and generally employ less

Table 1-3 Hourly compensation for shipyard workers worldwide (U.S. \$)

Country	1975	1980	1985	1990
United States	6.85	11.25	14.62	15.66
Canada	6.35	9.24	11.94	16.93
Hong Kong	1.05	1.67	2.32	3.78
Japan	3.92	6.75	8.12	15.04
Korea	0.54	1.65	2.13	6.52
Singapore	1.20	1.95	3.20	5.16
Taiwan	0.57	1.54	2.46	7.50
Belgium	8.75	15.75	10.71	N/A
Denmark	7.04	11.90	8.60	19.37
Finland	5.73	9.15	9.14	23.19
France	5.13	10.23	8.86	16.43
Germany	7.22	14.02	10.91	23.45
Italy	5.82	9.17	8.48	18.87
Norway	N/A	12.50	11.28	21.92
Sweden	8.08	13.22	10.03	20.93
United Kingdom	3.74	7.52	6.45	13.21

From U.S. Bureau of Labor Statistics, Nov. 1991

than 100 people. Topside yards usually have the capability of transporting men and material to the work site.

The U.S. ship repair industry continues to be very active and competes very aggressively in both domestic and foreign markets. The U.S. shipyards benefit from their location in the United States (the world's most important trading nation). Therefore, location, timeliness of repairs, and better pricing can, and do, give the U.S. yard an advantage over foreign competition.

The final element of the industry is the group known as "second-tier" shipyards. These yards are primarily engaged in supporting inland waterway and coastal carriers. Their focus is the construction and repair of smaller vessels, e.g., supply boats, tugboats, ferries, fishing vessels, barges, and small military

and government-owned vessels. This segment of the industry had surplus capacity during the 1980s and into the 1990s. But this excess has disappeared, and the industry segment is expected to have growth and firm prices into the 21st century [8].

3.3. The U.S. Shipbuilding Market

The shipbuilding industry is unique among all U.S. manufacturing and construction industries. First, since 1960, the industry has played a negligible role in the world market for merchant vessels. Second, the only domestic customers for ships has been either the U.S. government or firms completely dependent on government policy. The navy is the major customer for U.S. shipbuilding; however, this sector is expected to decrease in relative importance. The countervailing

effect of the Navy construction program was an important factor in keeping part of the industry alive since the mid 1970s. The U.S. Navy shipbuilding program is the largest in the western world. The Navy construction program, bolstered during the 1980s by the goal of attaining a 600-ship Navy, provided a significant boost to some U.S. shipbuilders. With the end of the Cold War, however, the Navy has sharply curtailed its fleet size requirement, and in early 1994 the fleet size was set in the range of 350 ships. The result has been significant reductions in Navy procurement.

In the early 1990s the Congress provided \$2.1 billion to the Department of Defense to begin a fast sealift ship acquisition program. A major component of the program is the acquisition (through either new construction or conversion) of additional sealift capacity equal to 20 large, medium-speed (24 knots) roll-on/roll-off ships. Initial awards occurred in 1993, with contracts being given to Newport News Shipbuilding, Avondale, and NASSCO. It is expected that construction/modification of the ships will continue through most of the decade.

In addition to the Navy construction program, the Navy is the source of approximately 50 percent of the dollar value of overhaul, repair, and conversion work done by commercial shipyards. This represents approximately 30 percent of the total Navy repair, overhaul, and conversion budget. The remaining 70 percent of this work is done in the eight Navy shipyards. The 30/70 split is based on an agreement between the Navy and Congress and has remained relatively constant over time.

Between 1950 and 1980, over 40 percent of U.S.-built merchant ships received subsidies, called Construction Differential Subsidies (CDS). This program provided a differential subsidy based on the difference between foreign and domestic shipbuilding costs (not to exceed 50 percent of the domestic cost).

In 1981 the Reagan administration terminated these subsidies, and the commercial shipbuilding market quickly disappeared.

The remainder of the domestic market is made up mostly of directly or indirectly subsidized ships. U.S. cabotage laws, called collectively the Jones Act after their principal architect, reserve all U.S. inland and coastal trade to vessels that have been built in the United States without CDS funds. For purposes of the law, Guam, Puerto Rico, and the U.S. Virgin Islands are also considered to be coastal, or cabotage, trade. Since the cessation of the differential subsidy in 1981, all of U.S. ships built for U.S. flag carriers, and not subsidized, have been Jones Act ships. Since 1981 less than ten ships have been built in U.S. yards—an average of less than one ship per year.

Reacting to the impact of the *Exxon Valdez* grounding off the coast of Alaska, the U.S. Congress passed the Oil Pollution Act of 1990 which requires ships and barges carrying petroleum products be double-hulled. That legislation has stimulated the new construction market, especially for double-hulled ocean-going barges and double-hulled barges for inland waterways. It is expected that there will ultimately be an impact on new ship construction, too.

In 1992 the Clinton administration established a working group to develop a proposal for a new maritime policy in an attempt to reverse the decline of the U.S. merchant marine, and to stimulate the redirection of the shipyards from military construction to commercial construction. The result was the passage of the Defense Conversion, Reinvestment, and Transition Act of 1992. The act had specific elements directed at revitalization of the shipbuilding industry, including (1) support for construction of ships that have market penetration potential, (2) the establishment of National Maritime Technology Centers to support technology transfer, and (3) cost-sharing of projects that will augment

and accelerate infrastructure changes. One of the objectives of the program is to achieve a 10 percent market share penetration in new ship construction by the year 2000.

Other government programs have included Title XI financing and two tax incentive programs, the Capital Construction Fund (CCF) and the Construction Reserve Fund (CRF). Title XI provided financing guarantees for merchant ships built in U.S. shipyards. The CCF and CRF assist operators in accumulating capital to build, acquire, and reconstruct vessels through the deferral of federal income taxes on eligible deposits. These government assistance programs, however, have been inadequate to sustain a viable market demand.

3.4. Resource Markets

Shipbuilding resource markets are very heavily influenced by the nature of the product markets. Price and lead times of material react to the cycles and small size of the product market. Similarly, the quality and availability of the labor force is shaped, both directly and indirectly, by these same factors.

3.4.1. Labor Force. The shipbuilding and repair industry is labor intensive, compared to all manufacturing industries. Within the industry, repair is more labor intensive than new construction. Ship repair is involved with smaller numbers of similar parts, and much of the work is accomplished aboard ship, where the opportunity for automation is reduced. Manpower skills used in new construction are basically the same as for repair, but the mix of skills is different. Shipbuilding employs more of the structural trades (including welders, burners, and fitters), while ship repair tends to use more of the outfitting trades.

Shortage of skilled labor is a continuing problem, particularly in the private sector. Possible reasons for this are relatively low wages, higher involuntary labor turnover

(layoffs), and few large-scale apprentice programs, relative to either Navy shipyards or related private industries. Because Navy shipyard workloads are planned in advance, and inflexible Civil Service regulations and manpower ceilings apply, Navy yard employment exhibits more stability than private yard employment. Navy shipyards, in their role as a support function to the Navy, must be able to respond quickly to requirements to repair and install highly sophisticated systems on short notice. The Navy shipyard apprentice training program ranks with the best in the country, and through specialization by each yard, highly skilled work teams are maintained for each equipment type used in the Navy. This investment in training is an important factor in attracting and retaining quality personnel.

Private yards, on the other hand, must be able to adjust the size of the work force to the workload. Higher involuntary turnover induces higher voluntary turnover, which is exacerbated by generally poorer work conditions and lower pay relative to other industries. Consequently, shipyards are reluctant to institute costly training programs, lest they end up training personnel for other industries.

Faced with a labor shortage, the usual initial response (adjustment) is to increase overtime and recruiting effort. Of course, the logical place to recruit is in the proximity of other shipyards. However, studies of shipyard labor indicate that it is relatively non-mobile compared to other industries.[9] Even when a pool of workers exists within one geographic area, recruiting may be ineffective. In a unionized area, pay scales are set by contract and incentives for changing yards are very limited.

Given a lack of mobility and the length of time required to produce a skilled craftsman, additional skilled workers may not exist in the locality and time frame in which they are needed. Management may then con-

sciously turn to skill dilution in order to reach numerical requirements. Skill dilution may take the form of increasing the ratio of trainees to journeymen, redefining what constitutes a journeyman, or some combination of the two.

If qualified mechanics are not available when demand increases, inputs to training programs must generally be increased. This is a reasonable short-run solution to a temporary shortage. However, the training of a journeyman may take anywhere from three to six years. Because of the cycles of the market and the length of market cycles, the period of increased demand may be shorter than the time required for training. In apparent response to this phenomenon, only a few shipyards maintain ongoing apprentice training programs. Notable exceptions include yards that participate in regional training programs and yards that have an isolated labor supply and lower-than-average turnover. They are generally able to meet their own needs for skill training through formal apprentice programs. Many yards rely primarily on the construction trades for basic skill training, and provide only minimum shipyard-specific training to new hires.

A labor shortage can occur because of an inability to retain workers as well as an inability to hire qualified personnel in the first place. Turnover, which measures retention (the sum of accessions and separations per 100 employees), is historically higher for private shipyards than for Navy yards or other industries, such as construction, which use similar skills.

In general, turnover is lower for industries using more highly skilled workers. Highly skilled labor is more costly to train and replace. Therefore, employers will endeavor to retain these workers. However, in the case of shipbuilding and repair, which is generally skill-intensive, this does not hold true. Shipbuilding and repair exhibits signifi-

cantly higher turnover than other, similar industries (not considering the Navy shipyards). This includes industries such as primary metal, fabricated metal products, transportation equipment, and aircraft. Additionally, wages in shipbuilding and repair are generally lower than for other competing industries, averaging about 15 percent less when compared to the aircraft, transportation equipment, and heavy construction industries. Past studies have determined that wages are higher in public than in private yards.

The shipyard labor market appears to be primarily influenced by the cycles of the product market. This is evidenced by high turnover, both "quits" and layoffs, and a general lack of formal apprentice training programs relative to other skill-intensive industries. Workers experience high layoff rates, which tend to result in high quit rates as well. Many workers who expect to be laid off take the initiative and migrate to other shipyards or other industries. [10] In general, wages are low relative to other skill-intensive industries, and this is reflected in high industry turnover. This situation is not necessarily true in many local markets. For example, formal training programs and higher wages prevail in Navy shipyards. However, only a few private yards invest heavily in training, primarily because of high trainee attrition and major fluctuations in workload.

3.4.2. Material. Depending on type, between 40 and 70 percent of the total cost of a ship is material and subcontracted services. The material market parallels the labor market, in that it is heavily influenced by the characteristics of the product market. However, in the short run, price and availability of material are more responsive to the effects of the economic activity in other industries. This is due, in part, to the relatively small shipbuilding market in the United States, compared to the overall industrial base. Manufacturing

lead times, another measure of the performance of the supplier base, have also generally exhibited the expected response to economic conditions. Thus, lead times will also be influenced more by general economic conditions than by the status of the shipbuilding industry.

The shipbuilding supplier base, along with other predominantly defense-oriented industries, has declined since the 1950s. The U.S. industry is, in several instances, dependent on a single supplier. Examples include suppliers of anchors, anchor chain, and activated rudders. In the case of quiet ball bearings used in submarines and many surface ships, the single source is a Japanese manufacturer. Reasons generally cited for the decline in the supplier base are:

- cycles and small size of the market
- costs associated with government regulations
- problems associated with military specifications/standards

The last two apply specifically to suppliers of military equipment but, because of the importance of the government market, affect the entire industry.

The effect of the size and cycles of the market received considerable Congressional attention throughout the 1970s.

However, very little has changed as a result of extensive testimony and some documentation by the Navy. Many subcontractors and component suppliers simply find it uneconomical to upgrade or even retain capacity for a market that is both small and sporadic. Additionally, the small subcontractors see a much more cyclical market than is apparent from observing the aggregate. When business is slack, shipbuilders tend to make components in their own facilities—components that would be subcontracted in times of greater demand. The result is an accentua-

tion of the feast-or-famine nature of the market for the lower-tier suppliers.

The cost of government regulations, including pollution abatement, became particularly significant during the 1970s. In most cases these costs apply across the board to all industries. Theoretically they should not adversely affect any one industry. However, compliance assurances are included in government contract requirements. This may result in suppliers of material to industries for which the government is the primary customer bearing a disproportionate share of the costs.

Military specifications/standards are a perennial problem for suppliers of Navy shipbuilding and repair programs. Manufacturers state that military specifications, in general, do not keep pace with the technological progress made by the industry.[11] Specific problems are:

- interpretation of requirements
- outdated specifications
- equally acceptable commercial components not qualified under military specifications
- unreasonable software/documentation requirements
- high cost of qualifying a product not commensurate with the expected return

3.5 Industry Organization and Performance

From an industry point of view, U.S. shipbuilding and repair can be characterized as a relatively small industry operating in a highly cyclical market controlled by the U.S. government. Technologically, the industry is somewhat backward compared to the aerospace industry, which is similar in terms of market structure. The economic value of the commercial side of the industry is minimal, and with few exceptions, ships can be purchased abroad more cheaply. Even the Navy has examined the feasibility of purchasing

ships outside the United States. The strategic value of the industry is well recognized, however, and maintenance of a peacetime shipbuilding industrial base is a practical necessity. The industrial organization and investment policies of the industry have evolved in response to signals from the government, and the structure of the industry is essentially a product of national maritime policy, or the lack of such a policy.

The industry is anything but homogeneous in terms of ownership, company size, and primary markets. However, some rough generalizations can be made with respect to profitability and capital budgeting policies. Beginning in 1959, the major shipyards changed from mostly independent firms to divisions of large corporations. With the exception of Todd, this transition was accomplished through conglomerate merger or acquisition by aerospace or other large companies.

The reasons for conglomerate merger are complex. In general, however, this form of acquisition is used because it provides a means of increasing the price/earnings ratio of the parent company, and offers scale economies in the capital market without running afoul of the antitrust laws. Either vertical integration or merger with a company that manufactures the same basic product line is often infeasible for large corporations because of the antitrust laws.

Whatever the particular corporate reasons for acquiring shipyards, it is not clear that such acquisitions were successful, based on usual economic standards. The business environment has been characterized as "one of high risk and low returns."^[12] Profitability has in general been low. It has been shown that profitability was two-tiered: medium-sized yards that retained their traditional old line shipbuilding identity were profitable, while those that were primarily aerospace oriented sustained consistent losses. It has also been suggested that cash flow rather

than immediate profits played an important part in corporate decisions to acquire shipyards.^[13] Throughout the period of conglomerate takeover, the Navy made progress payments weekly, while most of the shipbuilders' bills were paid monthly. Such "free loans" would be an important source of financing for the parent company. Due to the labor-intensive nature of shipbuilding and the fact that little capital investment was required for the shipyards when they were purchased by conglomerates, the opportunity existed for a high ratio of profit to invested capital. This, coupled with relatively low purchase prices, made entry into the shipbuilding industry attractive to conglomerates.

In retrospect, the capital budgeting policies of the major shipyard companies indicate a fairly consistent pattern of miscalculation. However, in terms of the signals emanating from the federal government and the world economy immediately prior to and after 1970, these policies appear very logical. Prior to 1970, investment in shipyards was very conservative. This reflected an industry for which the market prospects were minimal. Most investment was aimed at maintenance of the ability to remain in the business of building ships rather than expansion. Foreseeable demand and potential for becoming competitive in the world market certainly did not warrant an expansionary policy. Control over the domestic market was virtually nil, and government policy did not indicate any major changes in demand.

Commencing in the mid to late 1960s, the Navy and the Maritime Administration signaled major changes in government policy. The Navy embarked on an effort to implement Total Package Procurement (TPP), whereby the prime contractor is responsible for all of the components of a weapons system rather than just the platform. Series production of a class of ships was intrinsic to the concept, as opposed to allocating a handful of ships to

each of several yards. The Navy hoped to shift management responsibility for the total weapons system to the contractor, and to gain efficiency through series production. From the viewpoint of the shipbuilder, TPP required more sophisticated management, the necessity of integrating several diverse technologies and product lines, and large financial resources. These were considered to be primary strengths of aerospace and conglomerate firms, which were consequently attracted to the industry.

Concurrent with introduction of Total Package Procurement, the Congress enacted a Maritime Administration program calling for the construction of 300 commercial vessels in the period 1970-1980. This program was predicated on a projected expanded world market, particularly for very large crude carriers and high technology ships, such as liquefied natural gas carriers. The MarAd 70 program, as it was called, also hinged on productivity gains through standardization and series production.

In apparent response to the Navy and MarAd incentives, the industry invested an average of \$200 million (4.5 percent of sales) annually between 1970 and 1978 [14]. This was a period during which industry profits were nearly nonexistent. It is estimated that in the period 1969-1976, the industry borrowed externally, or from the parent companies, approximately \$800 million, while earning profits of less than \$50 million. To put this in perspective, this means that the industry took on a long-term debt equal to 2.5 times its net worth. The MarAd 70 program was not successful, resulting during the 1970s in construction of only 80 new ships and the conversion or reconstruction of 56 ships. With the subsequent collapse of the commercial market, and failure to achieve the higher profits commensurate with the added risk assumed under TPP, the financial position of much of the industry was shaky at best.

Shipbuilding is two tiered: it is a defense industry, but there is also an important commercial side to the market. Defense industries are characterized by a lack of control over markets and a consequent adversarial relationship between producers and customer. Even much of the commercial side of the shipbuilding market is controlled by the government. Profitability and capital investment are therefore highly responsive to government policy.

The decline of military construction will require a fundamental change in the industry's organizational structure, even more dramatic than that which occurred with the termination of the subsidy support program in 1981. It appears that by the turn of the century the U.S. shipbuilding industry will have reduced its employment by at least 40 percent from what it was in 1990.

The survival of any specific shipyard will be perhaps attributable to two primary factors. The first will be the ability of the yard to maintain its military market. This factor will undoubtedly impact Newport News, Electric Boat, Bath Iron Works, and Ingalls. Newport News, whose parent corporation is the largest of the shipbuilding conglomerates, also enjoys a position of some market power, compared to most of the industry. Newport News is one of the three nuclear yards and is the only builder of aircraft carriers. Electric Boat is dedicated to building nuclear submarines, and will probably maintain that assignment. Bath Iron Works is the lead yard on the Burke-class destroyer. And Ingalls is the lead yard on the Aegis cruisers.

The second factor is the ability of the shipyard to develop and maintain a commercial ship market. In this instance, the factors favor the smaller, more agile shipyards, or shipyards that can more easily leverage from their military ship construction program into commercial ship construction. Yards that will survive as a result of this second factor might include Avondale and NASSCO, who cur-

rently dominate in the construction of naval auxiliary ships, or McDermott and Trinity, who have had extensive experience in the construction of ships and platforms for the offshore industry.

An observable response to government market control is conservatism, both technologic and economic. This is evidenced in the defense industries by slow growth rates, low profitability, and apparent inability to market high-technology products in the more profitable civilian markets.[15] The structure and performance of the shipbuilding industry has been greatly influenced by government policies that have been implemented on a regular basis during the last 50 years. It remains to be seen what is in store for the industry in the future. Government policy will certainly play an important role. However, many shipbuilders have embarked on a course of investing in innovations in management and processes geared to operating efficiently in diversified markets. In the final analysis, the performance of the industry will be determined by the success of these innovations.

3.6. Technology Developments and Productivity

Efficient production in any industry depends on the nature of demand for the product and the relative prices of resources. Much has been written about labor intensiveness and capital formation in the shipbuilding industry compared to other industries. Similarly, shipbuilding technical processes and labor intensiveness in the United States have been measured against foreign shipbuilders. The conclusions have generally been that U.S. shipbuilding is more labor intensive than other U.S. industries and foreign shipbuilders. Such comparisons are meaningless, however, by themselves. The economic performance implications of labor intensiveness can be evaluated only in the context of resource and product markets

Although labor rates have shaped national policy, they do not explain the labor intensiveness of the industry nor the low productivity compared to foreign shipbuilders and other construction and batch manufacturing industries. The U.S. government has shaped demand, and demand has guided technology and capital formation. The demand for ships in the United States has historically been uneven and, more importantly, uncertain. Demand is based on the underlying world demand for shipping and national defense requirements, both highly cyclical, as modified by the political and economic climate. Additionally, in an attempt to broaden the shipbuilding base, Navy acquisition has traditionally been spread among several builders. Programs comprising 20 and 30 ships have been allocated to as many as seven shipyards. The fragmentation of orders and ensuing uncertainty did not offer incentive either to modernize facilities or reorganize production. The result was a high-cost labor-intensive industry.

In the late 1960s and 1970s, the Navy initiated acquisition policies, such as multi-ship contracts, intended to encourage investment in shipbuilding technology. In addition to Navy efforts to provide incentives for modernization, the Maritime Administration developed standard ship designs to promote multi-ship construction programs. Through the National Shipbuilding Research Program, the Maritime Administration also conducted an active education and technology transfer program in conjunction with the shipbuilding industry. The industry responded to these policies and has made major organizational and technological changes over the past ten years. Despite significant capital expenditures in the 1970s, an overall decrease in productivity during approximately the same period was reported to be between 15 and 35 percent [16] The United States is recognized as

a leader in the construction of nuclear and conventionally powered naval combatant ships. But in terms of man-hours and dollar costs, productivity has also continued to decline in this sector.

In late 1979 a team of six individuals experienced in shipbuilding visited six Japanese shipyards [17]. The visit was intended to identify low-investment, high-return shipbuilding technology. The purpose of the study, and subsequent reports published by members of the team, was to "encourage U.S. shipbuilders to adopt the observed advanced techniques for the purpose of improving productivity." Primary reasons cited for high productivity were:

- the utilization and application of the logic and principles of zone planning and construction
- the development and use of a very effective material classification scheme for definition, procurement, and control of material
- the extensive use and continued development of high-quality shipbuilding standards and modules
- the rationalized development and use of effective cost/man-hour-reducing computer aids

A key element of the above list of reasons for high productivity is that they do not depend on large orders and series production. The list does, however, highlight the principles of group technology through block construction based on zone, problem area, and stage.

In 1994, a project was completed that had conducted a comparative survey of major U.S. and selected foreign shipyards [18]. The survey indicated that U.S. shipyards, on average, employed lower levels of technology than that found in five foreign yards in all eight major functional areas that were examined. Importantly, the gap in technological differences had increased from a level that

was found in a similar survey conducted in 1978 [19].

The functional areas that were evaluated were: outfit production and stores, design/drafting/production engineering/lofting, ship construction, steelwork production, organization and operating systems, layout and environment, and other pre-erection activities. The largest differences were noted in the first two (outfit production and stores, and design/drafting/production engineering/lofting). There was a medium gap in the next three (ship construction, steelwork production, and organization and operating systems). The smallest gap existed in the last two (layout and environment and other pre-erection activities). The study concluded that even though U.S. yards have lost ground compared to their foreign competitors in the sixteen years between 1978 and 1994, there were some reasons for optimism. Labor costs and average hours worked for U.S. yards are world competitive. Additionally, technology improvements needed are generally of the soft or management technology type, rather than facility or hardware type. Thus, major capital improvements are not required to produce major productivity improvements.

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SHIPBUILDING MANAGEMENT THEORY

1. Introduction

The theoretical, economic model of shipbuilding introduced in this chapter is based on theoretical and empirical analyses of shipbuilding programs carried out in U.S. shipyards in the 1970s and 1980s [1]. The model will be used to highlight major cost drivers in ship construction and to show how costs can be controlled through improved organization of the work.

Shipbuilding work can be organized using

general principles of group technology, which are introduced and related to the traditional economic model of shipbuilding in the second section of this chapter. Two work breakdown structures, one system-oriented and one product-oriented, are described in the last section. The product-oriented work breakdown structure (PWBS) is the vehicle for applying group technology to ship construction. PWBS will be explored in depth in Chapter III.

2. Shipbuilding Economic Theory

The shipbuilding model is based on the theory of production applied to a production run for a predetermined, fixed total output. When total output is fixed, the producer's decisions include the production rate and when to start and stop production. These decisions are, of course, interdependent; when any two are made, the third is determined. Total output is fixed at the time of contract signing. The times to start and complete production are generally determined as part of the shipbuilder's bid, subject to some modification as a result of final negotiations. Consequently, the average production rate is also determined. However, traditional shipbuilding, compared to most manufacturing industries, is complicated by two important factors. First,

production rate varies over time according to the stage of completion. Second, ship cost estimating is inexact and as construction proceeds, production rates have to be adjusted. Consequently, this shipbuilding model reflects the effects, on total cost, of production rate changes over time. These effects, and the underlying variables which determine production rate, will be examined in detail as the model is developed. This model has been used to analyze and explain cost overruns in shipbuilding programs. It is used here to gain insights into cost drivers and how costs might be controlled using better production management techniques.

Defining a production function for shipbuilding entails three basic but essential con-

siderations: (1) defining a measure of output, (2) the time dependence of production costs on resource utilization, and (3) the effect on ship production costs of changes in production rate.

Ships are often produced singly or in batches of a few over a period of years. Therefore, it generally does not make sense to treat an individual ship as a unit of output. Usually output is measured as percentage completion of the ship. This is a very subjective measure and depends heavily on assumptions about the work content of all the components which make up the ship. Components, called work packages, are estimated to require some number of man-hours, according to certain industry or shipyard standards. The actual required hours vary according to when and in what order the work is done, and what other work is being accomplished in the same geographic area of the ship. Additionally, the required man-hours for work packages are in fact budgets. If a work package is not complete when the budget is used up, there is a tendency to "borrow" man-hours from other jobs and credit them to the work package which has overrun its budget. In effect the shipbuilder starts with less than an exact estimate of the number of man-hours required to build the ship, and then attempts to measure progress by counting inputs (man-hours).

Progress is also cross-checked using actual physical completion, such as feet of pipe installed, tons of steel in place, or number of compartments closed out. However, these are not homogeneous units. A ton of steel is not necessarily equivalent, in terms of output, throughout the same ship. Such a measure is even less meaningful when used across different ship designs or types. "Equivalent tons," used by many authors, is based on the work content of a ton of steel in some theoretical ship type (see glossary). This assumes like capital and work processes across shipyards, another shaky assumption.

The second and third major considerations, time dependence and production rate effects on cost, are particularly important to this discussion. A ship consists of many intermediate products, called work packages. A work package consists of some number of required man-hours. An increase in required output implies an increase in number of work packages or an increase in required man-hours per work package. The optimum erection sequence implies the availability of each completed work package at a specific point in time. Completed interim products (work in process) represent significant inventory costs. If interim products are completed too early, capital is tied up in the form of value added, and storage costs may be increased. Interim products generally require more expensive storage facilities, corrosion control, and security than raw materials. Late completion of interim products results in bottleneck delays and interference among work packages which were originally scheduled for different time periods. Similar problems can be anticipated if material or equipment that is supplied by vendors outside the shipyard arrives too early or too late.

The shipbuilding progress curve is S-shaped, as shown in Figure 2-1(a). This implies a bell-shaped production rate. If production proceeds according to plan, the production rate curve corresponds to the rate of resource application, as shown in Figure 2-1(b). In the early stages of ship production, steel is being cut and formed. At this time, outfitting is limited; the work area is limited by shop and platen space, and these determine the optimum production rate. As erection proceeds, more resources can be applied in the form of simultaneous prefabrication, fabrication, erection, and outfitting. This corresponds to the central portion of the curve shown in Figure 2-1. Later in the cycle, the work area is again severely restricted. A limited number of workers can be in the same

compartment, and many operations, such as painting and welding, are completely incompatible. The rate of resource utilization (production rate) therefore decreases during the last half of the construction cycle until it again reaches zero.

Optimum construction rate is determined by several factors which include fixed costs, work space, inventory costs, and changes in the construction rate. The latter factor will be discussed in detail below. In addition to the cost of capital and the usual overhead items, fixed costs include security, fire watches, corrosion control, and some support crafts. A ship sitting in the yard incurs these costs whether work is being accomplished or not. Consequently, these costs lead to a shortening of the optimum construction time. This effect is countered by costs associated with increased construction rate. As manning and construction rate are increased, so is interference among the crafts. This effect tends to lengthen the optimum construction time.

Figure 2-1(b) can be interpreted as either production rate (output per unit time) or required labor hours (manning) per unit time as long as actual production corresponds to planned (optimum) production. If interim products are not available as early as planned or if changes to plans or specifications add required resources at any point in time, then the time path of construction is no longer optimum. In other words, a truly optimum plan leaves no room for shifting resources to a different time period. Such a shift would by definition result in local interference among crafts. To compensate for "unavoidable" schedule slippage, the actual time path of construction usually allows some slack. In creating flexibility, the schedule departs from the theoretically optimum time path. However, it will be shown in the remainder of this chapter and in Chapter III that flexibility can also be gained through better or-

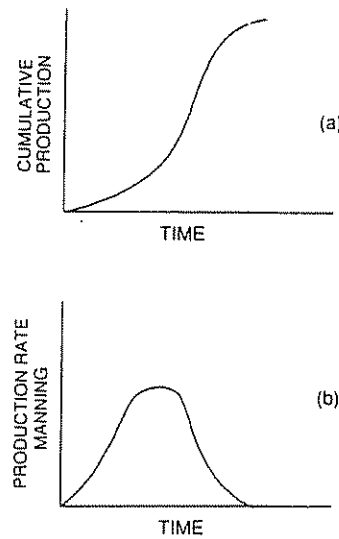


Fig. 2-1. Production plan for traditional ship construction

ganization of the work and tighter control of resources and work processes.

The dynamic shipbuilding model presented in the next subsection explains the combined effect of resource market phenomena presented in Chapter I, and changes to the originally planned production schedule. The optimum construction rate over time depends on fixed capital, the quantity and quality of workers, required changes to the original plan, and changes in the number of workers. During the construction of a ship, or a series of ships, only changes in the number of workers are generally controllable by the shipbuilder. The model is used to show how factors not under the control of the shipbuilder may disrupt the construction process and reduce productivity, and how this disruption is traded off against delay. It will be shown in Section 4 that many of the adverse effects of these factors can be reduced or eliminated using group technology.

2.1. The Shipbuilding Model

Once a ship, or series of ships, has been contracted for, the shipbuilder's incentives

are to produce the ship(s) in the specified time period at minimum cost. Wage rates are generally not controllable by the firm, different crafts are not usually substitutable, and most material is contracted for in advance or supplied by the owner. Consequently, cost minimization is essentially equivalent to minimization of total labor costs.

Shipbuilding is assumed to consist of many (n) discrete operations or tasks. The output of most of these tasks is an interim product, which is an input for a subsequent product. Each interim product is called a work package. Output is defined in terms of the number of work packages required. The total required output (Q) is the sum of all required work packages (n).

Progress on the ship is measured as the ratio of output at time t , Q_t , to required output. This is just the number of work packages completed at time t , (WP_t) divided by the number required. The units of output can also be thought of as "standard man-hours" (SMH). For example, suppose a particular task (say, the installation of 1,000 feet of pipe) is expected to require 200 man-hours. One thousand feet of pipe actually in place is then equivalent to $Q=200$ standard man-hours of physical output. Note that the number of actual man-hours used to install the 1,000 feet of pipe in the example may or may not be 200. Progress at time t is simply:

$$\pi_t = \frac{\text{number of work packages completed at time } t, \text{ in SMH}}{\text{number of required work packages, in SMH}}$$

In shipbuilding terminology, π_t is percent physical completion or just percent completion. Note that work packages are assumed to be of uniform work content. This is a simplifying assumption which is generally not true in shipbuilding. Work packages of uniform work content are a goal in group technology shipbuilding for reasons which will be explained later.

Figure 2-2 is an example of a ship production progress curve. In this example, the ac-

tual time is t' . At this time, planned progress is about 40 percent. Actual progress is about 35 percent, while actual man-hour expenditures are nearly 60 percent of the total man-hour budget. The variance indicates that some work packages are requiring more man-hours than were estimated and budgeted.

2.1.1. Production Relationship. A stable production technology across operations is assumed, and work packages are defined to consist of the same number of required standard man-hours. It is assumed that the rate of production at time t , q_t , depends on the level of manning and capital facilities.

Rate of production in shipbuilding is also dependent on changes to the production plan, either because of customer-initiated changes to plans or specifications, or because of estimation or scheduling errors by the builder. Changes may require additions to the required number of man-hours per work package or to the number of work packages. They may also require rescheduling of work to a different time frame than originally planned. The rescheduling of work and the physical interface of changed work with unchanged work may cause disruption of the production

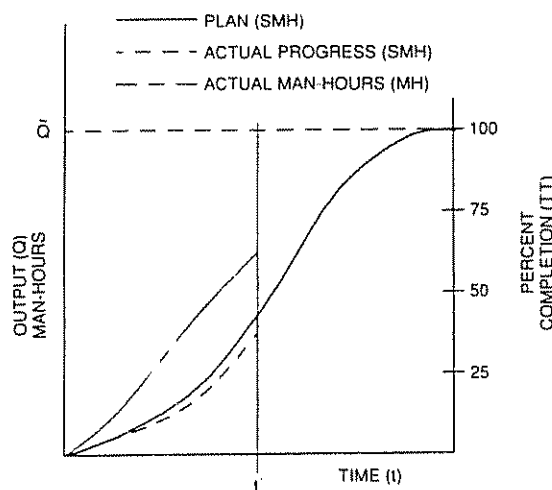


Fig. 2-2 Sample ship production progress curve.

process throughout the ship. It may also result in spillover effects on other ships or programs.

These assumptions can be stated as a standard production function.

$$q_t = q(K_t, L_t, E_t)$$

where:

K_t = rate of use of capital at time t

L_t = rate of use of labor at time t

E_t captures the efficiency effects of changes to required output. The components of E include the effects of incomplete or missing plans, disruption of workers or support services, and worker morale.

Physical output rate, q_t , is measured in terms such as feet of pipe installed or tons of steel erected per day. However, a measure of output rate is needed which will allow a comparison of tons of steel and feet of pipe. The units for production rate are "standard man-hours" per unit time. A standard man-hour is the amount of physical completion which should be accomplished by one worker working one hour if all of the other determinants of productivity are as originally planned.

In the long run the shipyard's capital and labor inputs can be adjusted to achieve the optimal size for the yard. The shipbuilder's choice of capital stock will depend on many things, including expected long-run demand and the need for flexibility. The size of the capital stock, in turn, will also determine the optimal rate of production for the yard.

In the short run, capital is fixed and output is varied by adjusting the size of the work force or the average length of the work day. Short run does not mean that the shipbuilder cannot change capital stock but rather that such changes are not sought because changes to required production rate are viewed as temporary.

Labor, L_t , is defined as quality-adjusted labor. Labor is not homogeneous, and the pro-

ductivity per unit time of a worker depends on many factors, such as:

- ship sequence number
- number of workers (manning level)
- time rate of change in the number of workers
- length of the work day (overtime)
- skill level of the workers

Ship sequence number measures learning which is expected to occur when more than one ship of the same type is built in the same yard.[2,3]

The number of workers (manning level) determines output directly. It also affects efficiency due to congestion and craft interference. If the manning level in a confined area is greater than the planned optimum, output per worker is decreased.

The time rate of change in the number of workers affects productivity because changes absorb resources that could be used in producing output. This will be explored in depth in the adjustment cost section below.

Skill level is a straightforward index of labor quality. It is often represented as the number of skilled workers (journeymen) divided by the total number of workers (journeymen plus apprentices and helpers). The greater this ratio, the more productive the work force is expected to be. There is, of course, some point at which productivity might begin to decrease, because there are too many experienced workers and not enough helpers to do the more mundane tasks.

Experience level is related to familiarity with the specific task at hand and crew integrity. Ship construction is accomplished by teams of varying size located at work stations. If the composition of these teams is not constant, crew integrity is lost and productivity is decreased. Workers newly transferred to a crew require orientation and on-the-job training, which reduces the productivity of

the crew. Experience level is commonly represented by total yard or craft turnover. Journeyman/total worker ratio and turnover are both commonly used predictors of productivity in shipbuilding.

2.1.2. Experience Curve Effects. The experience curve is the name applied to an observed relationship between costs and accumulated experience. It is related to quality adjusted labor, as defined earlier, and is used for a variety of operating management purposes, especially in the areas of planning and cost control. The concept of the experience curve can be expressed, mathematically, as follows:

$$\bar{Y}_x = a/x^b$$

where:

- $\bar{Y}_x$ = the average cost of "x" units produced
- x = number of identical units
- a = the cost of the first unit produced
- b = an exponent that varies with the complexity of the ship

The experience curve indicates that the average cost of all units produced declines at some constant rate as a function of accumulated experience. The term is now defined as the percent improvement that occurs in the average cost of all units produced each time the accumulated unit production is doubled. In the shipbuilding industry, the experience curve benefit has generally been found to be in the 5-10 percent range. It should be noted that while unit costs (exclusive of inflation) tend to decrease, the reduction is not automatic. Such cost decreases can, in fact, result only from the actions of management.

The reasons underlying the experience curve effect include:

- learning
- specialization
- investment
- scale effects

As described earlier, people learn to do tasks better and more efficiently as they become more experienced. Labor costs per unit decrease with accumulated experience. This is the well-known learning curve for labor which has been documented in management literature. (It should be noted that the formula, shown above, would also apply in developing learning curve benefits, except that the costs would be expressed in labor units, rather than in monetary units.)

When two or more people are involved in the same task, it is often possible to break that task into two or more parts. Then, for a given output, each person does his respective task more often. This specialization of task permits each worker to accumulate experience twice as fast as before. From the learning curve effect above, costs should then decrease faster than otherwise would be expected.

Capital effectively invested to increase productivity (as opposed to capital invested to increase capacity) also contributes to the cost reductions. This aspect of capital investment is also included in the experience curve.

Scale effects can occur in many different ways. For example, volume discounts on material purchases, etc., might lower unit cost. The overall effect of increased output on cost, however, is complex and often uncertain.

The experience curve is a relatively simple means to predict cost reductions. (Likewise, the learning curve is a mechanism for predicting labor reductions from learning a process.) In application the principal problems encountered are those of defining cost elements and defining the units of experience. In shipbuilding, recognition must also be given to the fact that all cost elements may not have the same experience base. For example, the experience curve effect may be different in the production of structural assemblies than that encountered in the production of outfit units.

The concept of the experience curve is particularly useful in strategic planning. For

example, consider the implications of the experience curve in terms of market share. According to the experience curve, the market leader would also have the lowest unit costs. As a result the market leader would also be in the strongest position to be the pricing and technological leader in the market.

2.1.3 Adjustment Costs. Adjustments to labor cause output to be less than is theoretically possible, assuming a particular production relationship and level of resources. This occurs because the adjustment absorbs resources which could be used in producing output. For example, more capital and labor are devoted to training when manning is increased. The resulting change in the span of control, particularly in middle level management, also results in decreased productivity. The resulting decreased productivity is generally referred to as frictional or internal labor adjustment costs. These adjustment costs are termed internal costs in contrast to external adjustment costs which are associated with market conditions.

Examples of external labor adjustment costs are severance pay, recruiting costs, or short-run increases in wages for a firm hiring from a relatively non-mobile labor force. Shipyard workers, in general, are geographically less mobile than other construction workers [4]. Thus, external adjustment costs can be expected to be important in shipbuilding. However, since man-hour costs are being considered, external adjustment costs should show up in the skill and experience variables.

The rate of change in the number of workers is of particular theoretical and practical interest. [5] Adjustment costs have the following characteristics: (1) both positive and negative adjustments to the work force may result in positive adjustment costs, and (2) adjustment costs are assumed to be convex. The first characteristic is straightforward for positive adjustments. A positive adjustment

would be expected to result in increased costs. In practice, negative adjustments may also increase costs. This phenomenon is partly the result of labor hoarding. Labor hoarding is the retention of workers who are not required for a particular output rate. Highly skilled workers are often retained during periods of slack demand because of the high cost of hiring equally qualified labor when demand picks up. Positive adjustment costs also occur because crew integrity may be lost when the work force is reduced. In the case of a general reduction in yard manning, it has also been observed that labor costs rise, partly because workers slow down in order to preserve their jobs. This is one of several reasons for the cost tail-up observed at the end of a program. [6]

The second property, convexity, means that adjustment costs increase at an increasing rate (increasing marginal adjustment costs). Convexity refers to the graph of the adjustment costs (c) versus the time rate of change in the labor force (dN/dt). This property is necessary in order for adjustment to take place slowly. For other than increasing marginal adjustment costs, the shipbuilder would attempt to adjust employment instantaneously. Such a practice does not agree with observed industry behavior.

2.2. Graphical Analysis of the Shipbuilding Model

The variables of the model presented above can be examined graphically in terms of simple one-period economic average cost minimization models. Total cost effects of labor adjustment are then shown in terms of varying the time path of production. Note that cost is merely the other side of the productivity coin. It is more convenient and perhaps more natural to address costs rather than productivity.

To ensure that a unique optimum average cost exists, it is sufficient that a producer have a U-shaped average cost curve. In a short-run model such as this, the U shape

results from the interaction of short-run fixed and variable costs. There are some costs whether or not work is being done on the ship. When the production rate goes up, these fixed costs are averaged over more and more units, so average costs (cost per unit output) fall. At the same time as the production rate increases, management costs rise and worker productivity falls, because more workers are sharing the fixed capital stock. Thus average costs fall as the output rate is increased to the optimum, and rise thereafter.

This simple model illustrates two important points. First, in the absence of labor adjustment costs, the optimum manning level should be attained instantaneously and maintained at a constant level throughout the construction period. Second, the optimum output rate determines the minimum average cost flow and total average cost. Once the optimum rate is chosen, the optimum construction period is determined. Thus, this model demonstrates that construction schedule decisions cannot in general be made independent of decisions to change required total output.[1]

2.2.1. Changes in Required Output. Required output can change for several reasons: initial estimates may have been too low; or the customer may require changes to plans or specifications after construction is underway. Required output may also increase because of unanticipated rework. This may be attributable to the production process itself or to reduced labor quality. Labor quality will be treated directly in Section 2.2.2.

Generally, initial estimates are lower than final ship costs. Customer changes also usually increase required output. These two factors are particularly prevalent in Navy shipbuilding programs. Contract changes may be initiated by the customer in order to incorporate newer technology, enhance safety, correct design errors and omissions, or comply

with higher-level directives such as environmental standards. Changes may also be proposed by the builder either to correct design deficiencies or to accomplish a given task at lower cost. A change may also be a "constructive change," resulting from some act or omission of the customer, such as customer-furnished material or documents that are late, defective, or otherwise different than originally specified. Additionally, required output may change because of natural disasters, such as hurricanes. Underestimating total required output may occur because of a tendency to "buy in," or bid low on an initial contract with the expectation of recouping any losses through follow-on contracts. Underbidding has also been shown to be a natural result of some contract forms because of risk-averse behavior of the bidders.[7]

One effect of changes to required output is often described by the term "disruption." In addition to the identifiable increase in requirements, changes in required output may have a compounding effect on efficiency over a number of ship systems, cost centers, or programs. Planning breaks down because the changed or added work must be done out of the usual sequence, and this causes scheduling problems in other parts of the ship or shipyard. If the added work requires a change in production method, it may have the same effect on learning as breaking the production run into a larger number of smaller production runs. The result could then be additional setup costs and greater total and average costs.

It is also possible that added work resulting from customer-directed changes can be done concurrently with the basic ship work and with little increase in capital requirements. This is equivalent to an increase in the business base for a yard with unused capacity. The result could be no change or even an increase in productivity. Curve A in Figure 2-3 shows the average cost for a hypo-

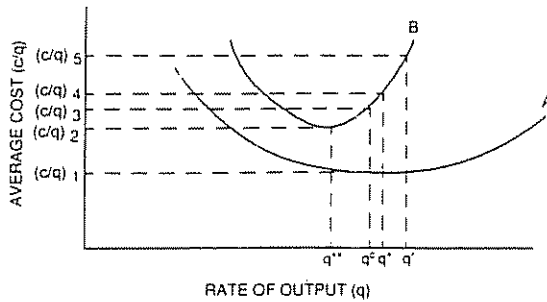


Fig 2-3. Shift in the average cost curve when required output changes.

thetical shipbuilding program as originally planned. The optimum rate of output is q^* , and the average cost equals $(c/q)_1$.

Assume that required output is increased. The disruption caused by changes shifts the average cost curve up and to the left (curve B). The optimal output rate falls to q^{**} , and the lowest average cost rises to $(c/q)_2$. The amount of the upward shift in the cost curve and the shape of the new cost curve B will depend on many factors, such as the construction phase in which the change is implemented, the lead time available to plan and schedule the added work, and the kind of work entailed.

Many kinds of shifts are possible. A shift could even increase the optimal rate of production. For example, a change could add work that could be done independently of other tasks such that it would pay to add workers to do the change work concurrently.

Figure 2-3 also shows four choices the shipbuilder could make with respect to the rate of output. The first is to maintain the initial rate of output, q^* . This requires lengthening the schedule. Because of the disruption caused by the accompanying schedule change, workers must be added just to maintain the previous output. A second option is to slow the program down to the new optimum production rate. This requires slipping the schedule even more. Production rate

q^c , a third option, requires no increase in manning or overtime. The difference in total cost between this choice and the original plan is the sum of the identifiable added work (called "hardcore cost" in the case of engineering changes) and what is called direct disruption. The fourth option is to maintain the schedule (production rate q'). This requires additional manning and/or overtime above that needed to maintain the original output. The added total cost incurred with this option over the previous choice is called indirect disruption. Indirect disruption cost, then, equals the additional costs (on top of hard-core and direct disruption costs) that result when manning or overtime is adjusted to accelerate the program. Note that the cost and schedule effects depicted in Figure 2-3 are in essential agreement with documented theoretical and empirical findings [1,8,9,10].

2.2.2. Labor Quality. Shipyards sometimes run into problems obtaining the number of skilled and experienced workers planned for a shipbuilding program. Three types of quality variables are considered: (1) worker skill, (2) worker tenure or experience, and (3) the amount of overtime hours worked. In terms of measurable variables, skill level is usually represented by the journeyman/apprentice or journeyman/total worker ratio. Worker experience is represented by labor turnover. Turnover is closely related to labor adjustment but is not perfectly correlated with it. Theoretical and empirical analyses have shown that the two variables can be treated as distinct. Overtime hours per worker or the average number of hours worked per week are straightforward measures of overtime.

The solid average cost curve shown in Figure 2-4 represents costs when output is varied and labor quality remains constant. In this example optimum output is q^* . The dashed curves illustrate two hypothetical

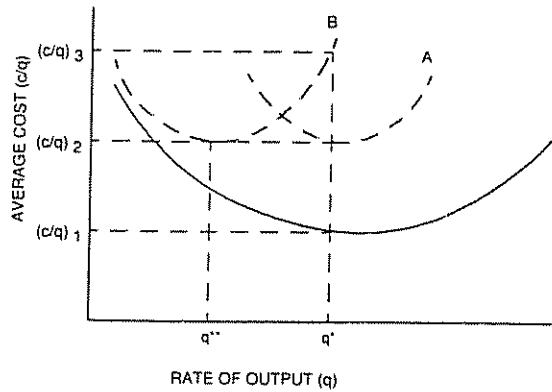


Fig. 2-4. Shifts in the average cost curve with changes in labor quality.

shifts of the short-run average cost curve resulting from a decline in labor quality. Both shifts imply increasing costs.

Suppose that the base cost curve in Figure 2-4 (solid line) was planned for a given shipbuilding program, and that, because labor quality is lower than planned, curve A or B is the actual cost curve. If A were the actual curve, the shipbuilder's average cost would rise to $(c/q)_2$, but the optimal schedule would remain unchanged. Curve A is particularly plausible if overtime or a second shift is used to maintain output at q^* . Overtime hours are generally considered less efficient because of fatigue (reduced labor quality) and they are more expensive. However, by reducing congestion and the demands on capital equipment, increased overtime may be used to maintain the optimum output level when labor quality is reduced. In other words, overtime in this case is efficient.

If B were the actual curve, however, the optimal output rate would fall to q^{**} . Minimum cost would rise to $(c/q)_2$, but, were the program kept on schedule, average cost would be $(c/q)_3$. The cost could therefore be reduced by slowing down the construction schedule. This is perhaps more usual, particularly late in the construction cycle, when congestion is most evident. In order to make up for lowered labor quality, workers must be

added to maintain the same output. This increases congestion and further increases cost per unit output. As a result the average cost curve shifts up and to the left.

This example shows that the optimal schedule can change because of changes in labor quality. Thus, the schedule is an important variable in controlling the effect of labor quality on the cost of a shipbuilding program.

2.2.3. Bottlenecks. Late delivery of material, plans, specifications, or subassemblies can cause "bottlenecks" in the production process. If any of these necessary inputs are lacking when a job is scheduled, the shipbuilder has to delay the job and other related work, or alter the schedule.

These bottlenecks are analyzed in terms of how they shift the average cost curve. As illustrated in Figure 2-5, the shift takes a form different from that shown in Figures 2-3 or 2-4. Curve A represents the base case, and q^* the optimal output rate. One response to a bottleneck is to stop work on the affected part of the ship, and lay off or shift workers. This eliminates the costs of rescheduling or workaround, but it slows down the overall rate of output. The output rate that can be sustained without rescheduling or workaround costs is labeled q' in Figure 2-5. Bottlenecks will shift the cost curve up to the

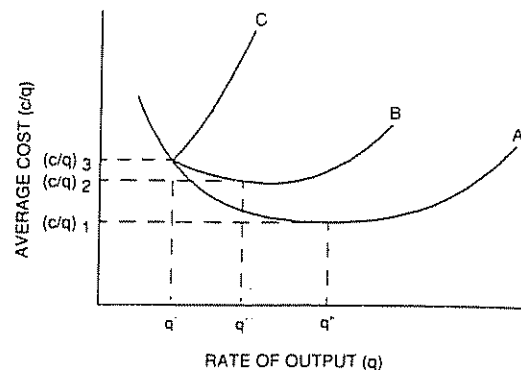


Fig. 2-5 Bottlenecks increase costs and reduce the optimal rate of production.

right of q' , but costs are not affected at output rates below q' .

Two hypothetical shifts of the cost curve are illustrated in Figure 2-5. Curve B illustrates a case where the efficiency costs of working around the bottlenecks are small. Although costs are higher than in the base case, it is still less costly to maintain output at q'' rather than cut back to q' . The optimal cost in this case is $(c/q)_2$. Curve C shows a case where the costs of workarounds are very large, and q' itself is the shipbuilder's least-cost alternative. If curve C rises very sharply, the shipbuilder has no practical choice but to reduce the rate of output to q' .

2.2.4. Adjustments to the Production Plan: Adjustment Costs. In Sections 2.2.1. through 2.2.3., average costs for a given single time increment were examined. In this subsection man-hour costs over the remaining production path, caused by production rate adjustments, are analyzed.

The shipbuilder's short-run production and manning paths are shown graphically in Figure 2-6. In this example the cost effects of the state of completion of the ship when a change occurs will be further developed. The effect of allowing the completion date to be a decision variable will also be demonstrated. The purpose of this exposition is to further develop an intuitive feel for the shipbuilding process and the alternatives available to the shipbuilder.

Figures 2-6(a), 2-6(a.1), and 2-6(a.2) show cumulative output, production rate, and manning level for the situation where the delivery date after the schedule is adjusted, t' , or is fixed at the original date, T . In Figures 2-6(b), 2-6(b.1), and 2-6(b.2), the shipbuilder is free to determine the final delivery date. The original time paths of output, production rate, and manning are shown as solid lines. It is assumed that these were chosen as optimal paths for the original output, Q . At time t_0 required total output is changed (or recog-

nized) by an amount, Δ . The builder must determine a new optimal manning level over time. This is done by determining the optimal path for the rate of change in manning and, in the second example, an optimal completion date. In the example, overtime will be held constant in order to highlight the independent effect of labor adjustments.

The "S curve" shape, typical of system-oriented shipbuilding, is assumed for this analysis. In the early stages, steel is being cut and formed. Production rate is limited by available shop facilities. In the middle portion, production rate first increases as more intermediate products become available to the work force. As erection proceeds, work space becomes limited and production rate decreases at an increasing rate. Toward the end of construction, the production rate goes smoothly to zero as the last work package is completed. Note that production rate may be in one-to-one correspondence with manning throughout construction. Total man-hours are equal to the area under the manning curve times the length of the work day, which is assumed to be constant for the original optimum plan.

- *Completion date the same as originally planned*

Under the production plan described by the dot-dash curve in Figure 2-6(a), production rate is increased above the original plan at time t_0 . The combined effects of decreasing productivity—resulting from greater than optimal manning and adjustment costs because of the more rapid increase and decrease in manning—results in a bulge in the manning curve. This bulge is displaced from the corresponding bulge in the production rate curve. The manning curve is displaced to the left and upward in the rising portion because of adjustment costs. Production lags manning in this region. At the apex, the manning curve is higher than the comparable produc-

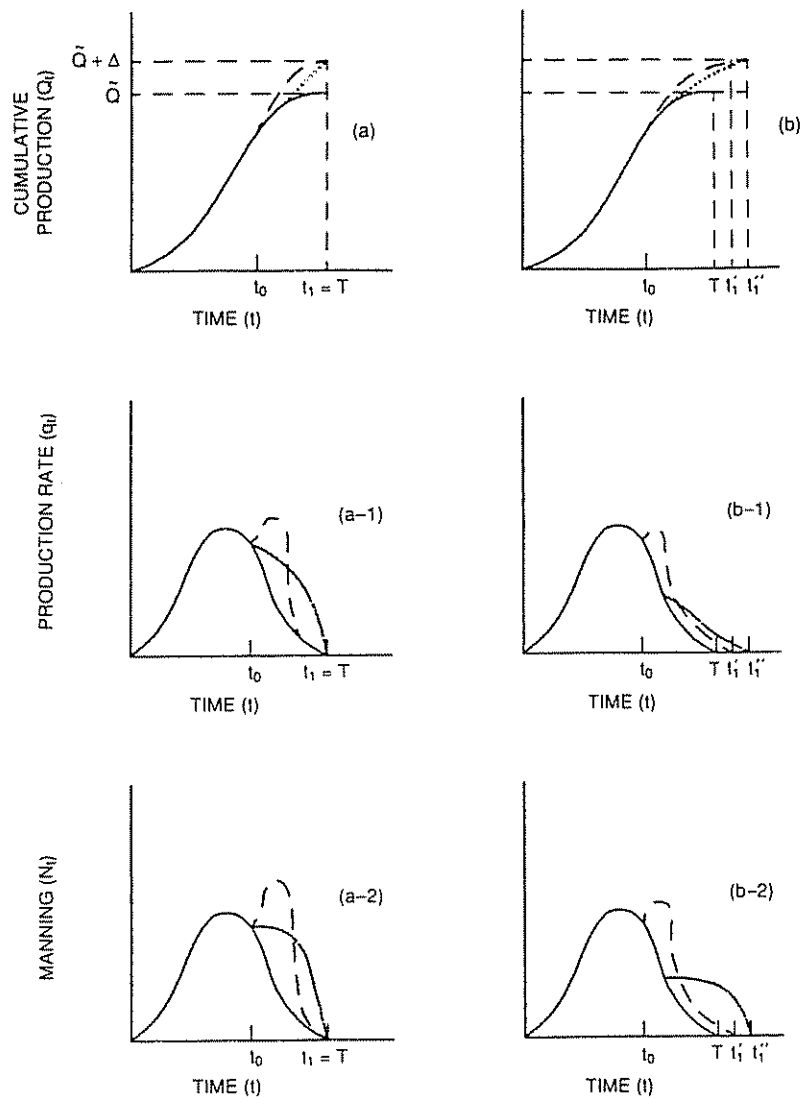


Fig. 2-6. Production plans before and after total output adjustment.

tion rate curve because of decreasing marginal productivity of labor.

As production rate is decreased, the manning curve is displaced more and more because of initial adjustment costs. As the manning adjustment decreases nearly to zero just before reaching time t_1 the manning and production paths approach the original planned optimums. Again, manning lags the production rate path.

The policy described by the dashed curve maintains production rate for a time at the originally optimal level. Because the work space is becoming increasingly restricted, manning continues to increase even though production rate is constant. This representation implies decreasing returns to a fixed factor where the fixed factor is work space. Here the rapid decrease in manning at the end of construction results in a horizontal

displacement of the manning curve due to increased adjustment costs. This displacement is greater than the corresponding bulge in the production rate curve.

- *Completion date determined by the shipbuilder.*

When delivery date is a control variable, the builder has more discretion in choosing the optimal production path. Figure 2-6(b) shows how the shipbuilder might balance the costs of manpower adjustments and the daily labor costs which accrue whether progress is being made on the ship or not. Corrosion control, fire guards, and overhead labor such as quality control or ship management contribute to these fixed man-hour costs. Because of such costs, the builder might find it economically efficient to man above the technically efficient level. The dot-dash path illustrates a case where fixed costs are relatively high. The builder chooses to incur greater adjustment costs by initially increasing production rate to a level above that originally planned. In this way, the costs of having the ship remain in the yard are reduced.

The dashed curves show the case where daily costs are lower relative to adjustment costs than in the previous example. This plan maintains production rate, for a time, at the original rate and then extends the period of construction in order to reduce the rate at which manning is reduced. The costs due to the decreased productivity of higher manning levels late in the construction period are greater, but adjustment costs are reduced from the dot-dash plan. Note that the plans shown in Figure 2-6(b) result in fewer man-hours overall than those depicted in Figure 2-6(a). This overall reduction in cost when construction time is extended illustrates the expected result of maintaining production rate more nearly the same as the original "optimum" rate.

2.3. Summary of the Shipbuilding Model

The shipbuilding economic model shows the highly detrimental effects of changing production rate once the program has been planned. It also shows the impact of unanticipated shortages in material or interim products, reduced worker skill level, increased turnover, or changes to the rate of manning on production rate. Changes in production rate affect cost. These effects are well documented and are the result of the breakdown of the planned production schedule, often to the point of loss of control over the production schedule by the shipbuilder. Schedule changes result in the need for higher manning levels, overtime, or both, later in the construction sequence, when interference between trades is more likely to occur.

The following summarizes the model:

- (1) For a given yard capital and for each time interval, there is a least-cost (optimum) rate of output, which yields minimum average costs.
- (2) Given capital, minimum total cost is realized by producing at the optimal production rate in every time interval. The optimum production period is determined by the optimal time path of production rate and the required total production at each point in time.
- (3) Reduced labor quality (skill level, worker tenure or experience, the number of overtime hours worked) will increase minimum average costs and may change the optimum production rate. Generally the increases in manning necessitated by lower labor quality require a reduction in production rate because of increased congestion. Overtime, which may be used to compensate for decreased skill level or experience, is generally less efficient because of fatigue and higher hourly wage rates. However,

overtime worked during off-hours (at night or on weekends) may be an efficient way to keep the ship on schedule because it decreases congestion and allows more intensive use of capital facilities.

- (4) Bottlenecks (because of late or missing plans or equipment) reduce optimum production rate and increase minimum average cost. Some bottlenecks are too costly to work around, and the delays they cause may delay completion of the ship.
- (5) Changes in required output (changes ordered by the owner or correction of builders' mistakes) increase minimum average cost and may also reduce optimum production rate. This occurs partly because congestion reduces productivity when manning is increased in response to the increase in required output.
- (6) Adjusting labor in response to changes in the optimal production rate results in internal adjustment costs. These costs occur because labor and management services which could be producing output are diverted to training or scheduling tasks. This means that in addition to the added cost caused by congestion after labor is adjusted upward, there is a cost of getting to the new level. This cost may be incurred when manning is reduced as well. This occurs primarily because of labor hoarding.

2.4. The Shipbuilding Model: An Example

Figure 2-7 demonstrates the effect on ship cost of the variables discussed individually earlier in this chapter. This example is representative of man-hour profiles for one ship in a multiship construction program. Average daily man-hours (planned and actual), average change in required man-hours, and average

overtime hours are plotted as functions of time after the start of fabrication for one ship. This chart shows some of the key elements of ship cost associated with traditional shipbuilding in an environment of changing requirements.

The graph shows significant changes in required production beginning shortly after the start of fabrication (A). Such changes to requirements are characteristic of "design instability." Design instability can result from customer-originated changes to plans or specifications, the discovery of errors or major producibility problems in the plans as drawn, or late or defective materials, components, or documents. Given a required increase in output, management can increase production rate (acceleration), or the length of the production cycle. Assuming capital is fixed, production rate can be increased by a combination of increased manning and working overtime. For the ship construction project depicted in Figure 2-7, management chose to accelerate the program in order to minimize delay. Acceleration combined with critical periods of performance for some changed work resulted in schedule inflexibility. This in turn meant that it was nearly impossible to maintain a reasonably constant level of resource usage.

Although significant increases to total output had been accumulating since point A, the original production rate was maintained until point B. This meant that a great deal of work was being deferred. At point B, the builder accelerated the program in order to get back on schedule. The remainder of the construction period was characterized by "compression" (greater than optimal production rates) as well as some design instability. Although it may not be readily apparent to the eye, the actual man-hour increase above plan is greater than the total change in required output. This means that productivity was lower than planned. A heavy cost was associated with the high manning levels used to attain the increase in production rate dur-

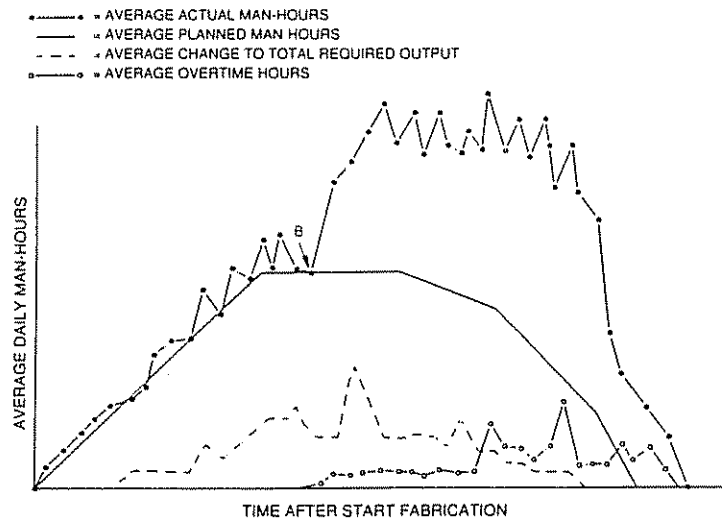


Fig. 2-7. Manpower profiles in an environment of changing requirements.

ing the last half of the construction period. This cost is caused primarily by congestion.

In addition to the costs associated with very high manning levels, considerable extra man-hours were expended in order to accomplish out-of-sequence work and in moving individuals and crews on and off the job. Note that throughout the period when required output was being changed, manning was fluctuating sharply. These fluctuations are typical of a program where design instability is significant. The rapid changes in resource level result in significant adjustment costs.

A second part of adjustment costs which is not as obvious from the graph is waiting time. The graph shows rapid shifts in manning. It does not show the instances when workers were waiting for access or for parts because of the breakdown in planning and

control associated with design instability. Nevertheless, the hours lost to waiting are a significant part of adjustment costs.

Overtime was concentrated in the latter stages of construction. This is fairly typical. This period is crucial in the shipbuilding construction cycle. Machinery and other systems are being interfaced, trials conducted, and final quality assurance milestones completed. The builder's choices become even more limited, because there is only so much physical space available aboard the ship. It is generally more efficient to reduce congestion and accommodate schedule changes by working overtime rather than increasing manning. This has been confirmed by empirical analyses of major programs, which showed that the partial effect of increased overtime is a reduction in total man-hours.

3. Group Technology

The economic model of shipbuilding developed in the previous section describes important cost drivers and the mechanics of cost measurement in shipbuilding. Knowing the major sources of costs and how to measure them, however, is not necessarily the same

as knowing how to control them. In this section the basis for controlling costs through improved management and production organization is presented. The means of organizing the work is the application of group technology.

3.1 Group Technology, an Overview

Group technology (GT), also called family manufacture (FM), began as an outgrowth of an attempt to develop a more efficient system of classification and coding for use in the management of industrial processes. As with any scientific endeavor, a classification system is essential to the organization of data in order to facilitate analysis and synthesis, the formulation of hypotheses, experimentation, deduction, and finally generalization to a practical application. However, the classification system is only a technique or tool of the scientist. Likewise, group technology is an innovation in the broader field of management of manufacturing processes, not just a technique for keeping track of material, parts, subassemblies, etc.

Group technology is also called cellular manufacture. The word "cell" conveys important information essential to understanding what group technology is and how it can be applied to shipbuilding. In the machining industry, where GT has been most extensively applied, a cell consists of some number of grouped machines and the people who operate them. Generally the operators are cross-trained to operate all the machines in a given cell. Instead of piece parts being scheduled sequentially, the cell is scheduled and loaded with parts which are classified according to shape, material, size, etc., into a "family." The cell is then effectively operated as a single machine. A part is essentially worked continuously from the time it is loaded into the cell until it emerges as a completed interim product. As a consequence, the time spent in process and the inventory level of work in process can be a fraction of what is normal for a traditional manufacturing layout and production control system.

In establishing families, an effort is also made to reduce the number of different individual parts. This may involve marketing as well as design personnel, since the salesman would generally like to be able to fill every

order no matter how low the level of demand or how unprofitable a given product line might be. Particularly in the case of custom-made products, this may involve "selling" the customer on the overall cost savings of production-kindly designs even though they may involve some degradation in operational suitability.

In addition to minimizing the number of individual parts and the number of operations, batch sizes are also reduced to the minimum. A major objective of GT is to reduce the inventory of work in process to only what is needed. This may sound like setup and teardown times will be excessive and that the risk of running out of some assemblies will be high. On the contrary, setup times within a cell are minimized, because cells are designed so that machines need only be adjusted rather than completely reset, and much tighter control of stock and work in process is maintained. The savings in stock and interim product inventory, often the single greatest component of variable cost, can more than compensate for added machine adjustment time.

An additional benefit is that job satisfaction tends to be high. Workers are cross-trained in all aspects of the cell, including inspection. When a cell is loaded, the workers actually see the finished products emerge within a short period of time. Additionally, schedule control can be maintained very closely so that there is very little if any unanticipated idle time. The result is higher morale and higher productivity.

Figure 2-8 is a comparison of a machine shop laid out conventionally and in cells. The conventional layout is based on grouping like machines, while the group technology layout is organized into cells that are structured to produce similar products. The complete machining of an individual part in the conventional layout requires considerable handling of the part, possibly back and forth between lathe, mill, grinder, and other machine type

areas. Thus the benefit of repeating many similar operations is balanced by the additional material handling, storage, inventory control, and work in process costs. For example, assuming a batch size of 100 and 4 minutes for each process, the conventional six process steps shown in Figure 2-8(a) require 2,400 minutes for each batch ($4 \times 6 \times 100 = 2,400$ minutes). Using the group technology process, Figure 2-4(b), the total batch in-process time is 420 minutes. The first part requires $4 + 4 + 4 + 4 + 4 + 4 = 24$ minutes. The remaining parts require $4 \times 99 = 396$ minutes, for a total of 420 minutes.

The group technology layout results in the more or less continuous manufacture of an individual part, within a single cell, by the same group of workers. Not only are throughput times greatly reduced for the layout shown in Figure 2-8(b), but the machine grouping enhances the cohesiveness of the workers in the cell. Expanding this approach to an entire manufacturing operation

produces the shipbuilding system to be described in this text.

3.2. Group Technology Defined

The purpose of addressing GT in this book is to help the reader better understand shipbuilding and how productivity can be improved in the shipbuilding industry. While the treatment will be rigorous with regard to the description of group technology, the emphasis will be on those aspects of GT which are applicable to and interpretable in the context of shipbuilding.

Group technology may be defined as:

The logical arrangement and sequence of all facets of company operation in order to bring the benefits of mass production to high variety, mixed quantity production [11]

This general definition emphasizes a systems approach to management, as opposed to a

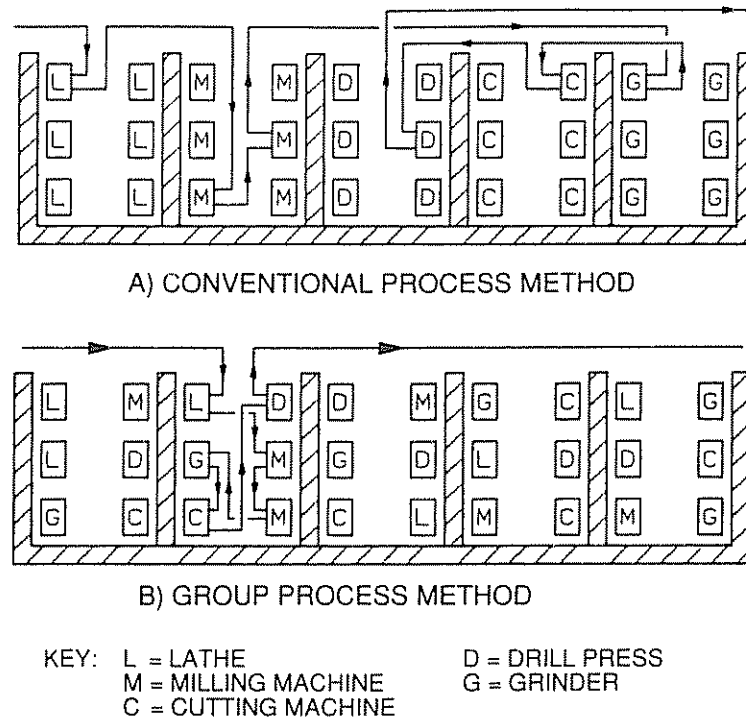


Fig 2-8. Comparison of conventional and group process batch flow.

technique for organizing a limited aspect of a manufacturing process independent of the total system. As such, it supports a crucial precept put forth by Mitrofanov in his pioneering work on the subject [12]

Mitrofanov stated that the group technological process is a variant of "... the systematization and generalization of the experience of the entire machine building industry ...". This book deals with the total management of a shipbuilding or repair activity. The group is the basic production unit of zone- or product-oriented ship construction. However, a crucially important characteristic of product-oriented ship manufacture and construction, which sets it apart from traditional shipbuilding, is the total integration of all departments in the company. As cited by Ranson, "There are only two people in a manufacturing organization, the man who sells and the man who makes; everyone else runs their messages." [11] The group is the basic production element. Everyone and everything in the yard should be organized to support the group.

A second definition of group technology provides further insight [13]

GT is a technique for manufacturing small to medium lot size batches of parts of similar process, of somewhat dissimilar materials, geometry and size, which are produced in a committed small cell of machines which have been grouped together physically, specifically tooled, and scheduled as a unit.

It is useful to analyze the essential elements of this definition:

- *Small to medium lot size batches*—Many of the interim products of shipbuilding are one of a kind or only a very few like parts. Group technology is not applicable to lot sizes which can be efficiently produced on an assembly line. Group technology is a means of realizing certain benefits of mass production (i.e., relative permanency of location and function, moving work to the worker, balanced product flow, etc.) for essentially small batch interim products. It is not mass production. Perhaps one of the major errors made by innovative shipbuilders in the 1960s and 1970s was attempting to adapt mass production assembly line techniques to what is a small-batch process. The result was yards which depended on series production with large, unrealistic throughputs in order to have any chance for efficient productivity. In essence, these yards depended on government manipulation of the market for productivity rather than adapting the production process to the existing and anticipated market. When the world shipbuilding market collapsed in the 1970s, many of the most modern assembly line type yards were the first to go bankrupt or be nationalized.
- *Similar process*—This implies categorizing interim products by "problem area." A "problem area" is a specific type of work, involving the use of similar production techniques, tools, and worker skills. For example, manufacturing curved pipe pieces and straight pipe pieces are two different problem areas. So too are flat panel and curved panel assembly. This will be discussed in greater detail in the next chapter.
- *Somewhat dissimilar materials, geometry, and size*—That the same problem area does not imply identical shape, material, size, etc., is a crucial concept. In a GT product-oriented operation, the installation of curved pipe and curved ventilation ducts may be the same problem area and be accom-

plished by the same crew. However, in traditional shipbuilding, these two operations, even if physically adjacent, would be accomplished at different times by different work crews.

- *Processed in a committed small cell of machines which have been grouped together physically*—In machining industries, where GT has been primarily applied, this is self-explanatory. In shipbuilding, the cell often consists of a crew of workers whose most sophisticated piece of equipment is a spanner wrench or a simple arc welder. The essential concept implied by this phrase is parallelism. A cell in a machining industry consists of a group of machines which complete all processes necessary to complete piece parts in a particular family, regardless of sequence or machine utilization. Similarly, in shipbuilding, a cell or group is responsible for completing all aspects of a given block or unit, including piping, ducting, painting, etc., regardless of overlapping functional systems. Consequently, subassemblies can be completed simultaneously, rather than systems being completed sequentially.
- *Specifically tooled*—In machining, this implies the use of equipment such as turret lathes, where tools need only be adjusted, never removed. Shipbuilding has the added advantage that the operator may be thought of as an essential part of the machine in some cases. Adjustment of tools may imply only moving the operator's anatomy.
- *Scheduled as a group*—This means that the cell or unit is scheduled as a single machine. In shipbuilding this is comparable to commencing work on a work package assigned to a given group (i.e., a subassembly or unit) only when all resources are on hand. This has important implications con-

cerning management, engineering, and material control. It means that the former must be responsive to production control in a way not normally expected in conventional shipbuilding.

3.3. Classification and Coding

Group technology is not synonymous with classification and coding. However, classification of the elements of production is perhaps the first step in the successful implementation of GT. The definition of group technology presented by Ranson is valuable because of its generality and applicability to all aspects of company operation. So too must a classification system be based on the assumption that all elements of the company are subject to classification and coding (see Figure 2-9).

3.3.1. Classification. The Webster definition of classification is "Systematic arrangement in groups or categories according to established criteria"[14] This definition is straightforward and suitable for the purpose of this discussion. A key word in this definition which perhaps requires some elaboration is "criteria." The hierarchical classification system used in botany or biology is familiar to every scientist. This system of classification is called the Linnean hierarchical taxonomy, after the Swedish botanist Karl von Linné. Organisms are classed into kingdom, phylum, subphylum, class, order, family, genus, species, and variety according to *mutually exclusive* and *permanent* characteristics.

Edward Brisch, a mechanical engineer and designer, adopted the decision tree type hierarchical classification system derived by von Linné, but added two principles or criteria. In addition to mutual exclusivity and permanent characteristics, he required that the system be *all-embracing* and based on the *user's point of view*[13] Brisch's taxonomy has become one of the standards for industrial application.

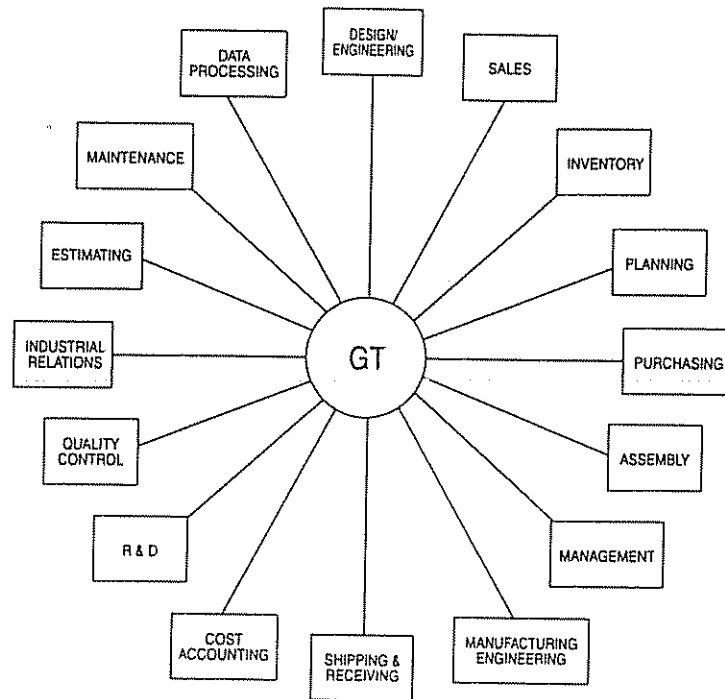


Fig. 2-9. Company functions affected by group technology

One classification system, the Product-oriented Work Breakdown Structure, is introduced in the last section of this chapter and will be treated in detail in Chapter III. In this subsection, general application of the above four principles is addressed.

- *User's viewpoint* — A classification system must be responsive to the objective of the next higher system of which it is a part. A primary application of a classification system is to define families of parts in order to facilitate engineering or manufacturing decisions. Shape might therefore be an important attribute. However, shape is important only as it relates to problem area or work process. For example, two nearly identically shaped parts might present two completely different problem areas because of differences in chemistry. Extrusion or

casting are two very different methods of producing identically shaped parts of different material. A familiar example is the classification of playing cards. A bridge player might categorize the population in samples of 13 cards arranged first by suit and second by value with the ace at the high value end. This classification system would be of little value to a poker player. For poker the population would be broken into samples of five or seven cards ranked according to certain combinations of cards, such as flush, straight, pair, etc. Within these classes ranking is determined by card value, with the ace high.

- *Scope of the classification* — A classification system must be able to accommodate the product, the means of production, and the controls over production. In line with the second principle, that the system be all-embracing,

the scope must be defined based on the population as well as the objective of the classification system. This means that numbers of categories must be sufficient to accommodate all of the characteristics which are of interest to the particular business. It also means that information should be stored and be retrievable according to the specific user. For example, a production engineer, a salesman, and a purchasing agent are interested in different characteristics, even though those characteristics might identify the same item. The supplemental characteristics required by different users must therefore be stored in the data base so that each user receives or inputs only the required information.

- *Mutually exclusive* — Any given set of identical characteristics must describe a unique object. This may seem too obvious to receive more than passing interest. In a company dealing with thousands of parts, however, it may be of more than academic interest. In the absence of a high level of discipline it is not uncommon to find the same part described by more than one set of code characters.
- *Permanent characteristics* — Permanence is, of course, relative to the user's point of view. In general, a permanent characteristic is one that describes what an object is, not how or where it is used. Where a pipe piece is used is important to an assembler, but there are ways of identifying where it is used which are distinct from the classification system. Material, size, and degree of bend, on the other hand, are permanent, easily identified attributes which affect design and manufacture decisions. Figure 2-10 presents an example of such

a classification scheme, as applied by the Boeing Airplane Company to the design and manufacture of commercial aircraft.[15]

3.3.2. *Coding*. Classification and coding are often used as if they were one word. They are not. The code is the vehicle by which a classification system is made operational. A classification system based on keywords, such as is used for some library searches, is feasible. In general, however, a code consisting of numbers, letter characters, or symbols is much more effective. A sequential numbering system should not be confused with coding. A code must not only identify an object, but must be based on permanent, mutually exclusive attributes according to some user objective. For purposes of retrieval and ease of use, it is desirable that the code reflect yes or no questions. An object either has a certain characteristic or it doesn't. This does not mean that codes must be binary. A particular hierarchical category such as size may be described by the digits zero through nine to describe ten different sizes.

Codes may also be mnemonic. Letters corresponding to the first letter of keywords may be used to represent certain attributes. For example, one shipyard uses IL10 to identify a ten-foot inclined ladder. Further examples will be given in Chapters III and VII, where coding will be discussed in more detail.

3.4. Group Technology and the Shipbuilding Model

It was shown in Section 1 that a major source of low productivity (high costs) in shipbuilding is unanticipated changes in production rate. This takes many forms (increased manning, overtime, rapid fluctuations in manning, idleness, etc.) and can be traced to more than one direct cause (poor cost estimation, design instability, bottleneck delays because of missing material or plans, high turnover,

etc.). The effect of such cost drivers is exacerbated by accounting and production control procedures which are oriented to functional ship systems. Functional system orientation contributes to a highly sequence-dependent production operation. For example, a fire main system spans nearly the entire ship. The labor and material required to fabricate and install a fire main system would not be difficult to estimate if the system were laid out in an open field. However, the system must interface both in time and space with the remainder of the ship. This creates a massive accounting and control problem. It also creates a practical problem having to do with human nature.

If a work order is issued for the entire system, as is common practice in many yards, it must remain open for nearly the entire construction cycle. This work order then becomes a prime candidate for "creative progress reporting" by various shops. Sometimes the man-hours and material budgeted for another work order are used up before the work is completed. A work order having a large budget and spanning a long time frame,

such as the fire main work order, then becomes a logical source of borrowed budget. Shop foremen simply charge resources expended for one job to the job with the remaining budget. It is something like a pyramid club. The final accounting can be deferred as long as some work orders are still open. The shop foremen, of course, hope to bring budgets into line through various efficiencies before the final accounting. Even if this is done, it is impossible to properly account for expended costs of some sections of the ship. As a result, estimating future jobs or even ships in the same series is very inexact. Additionally, areas where productivity might be improved may be disguised. Management doesn't know that such areas are contributing to costs in excess of what was planned. Consequently, no effort may be made to correct the situation.

Another source of low productivity is idleness. A major source of idleness is a breakdown in resource scheduling and control. Workers report to a job and find someone from another trade in their way because of a lack of schedule coordination. The workers

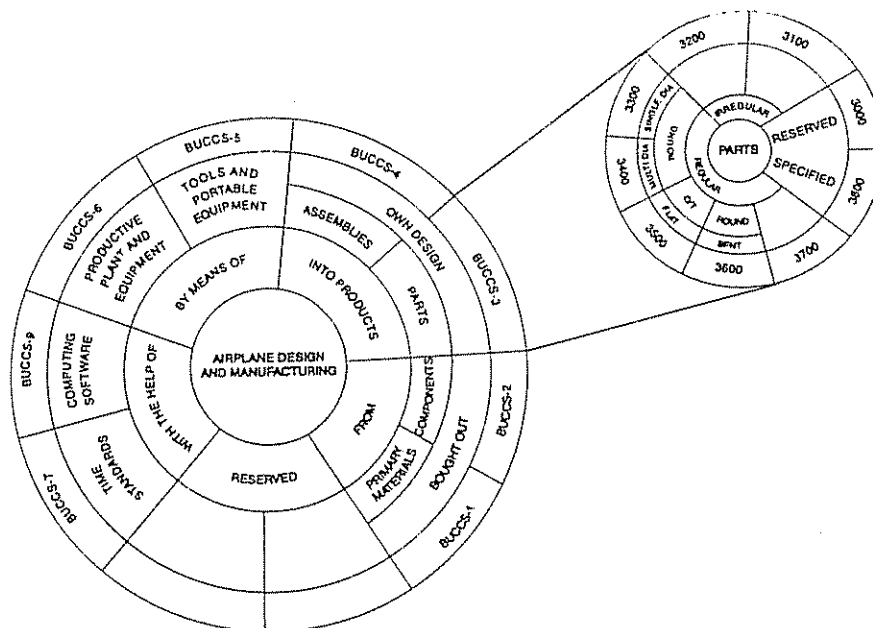


Fig. 2-10. The Boeing Company group technology classification system, based on the E. G. Brisch concept (Note: BUCCS refers to Boeing unified classification and coding system)

wait. Or workers need some part to complete a task. One goes to find the part. The rest wait. Drawings are not available as needed or a change to the drawings is incomplete. The workers wait. A critical previous task is not completed, or some owner-provided equipment does not arrive on time. The workers wait. The list goes on and on.

So, too, the list of apparent causes of low productivity goes on and on. What is important is that these are inherent in the management system, not in the performance of the individual workers. Borrowing man-hours and idleness are not an indictment of the work force as sneaky and lazy people. Rather, the indictment is against the management system. Group technology is one possible approach to improving the management system.

If the ship is subdivided into smaller geographical areas (zones), then the master schedule never has to be concerned with the many interfaces between the fire main system and all the other systems on the ship. These zones represent the output of a GT cell or group. The cell is then loaded with all of the resources necessary for the completion of some manageable work package. Such a work package may include a portion of the fire main system, along with ventilation ducts, electric conduit, etc. If problems with the plan and schedule develop, such as resources not becoming available as planned, management should be able to recognize and respond to the situation without adversely affecting the rest of the project. For example, the delayed work package may be deferred and another package loaded. Most of the idleness problem then disappears.

An important effect of zone construction is to straighten out the S curve described in Section 2. Hull construction and outfitting are accomplished concurrently. This allows a steeper progress curve in the beginning and final portions of the building cycle, and a reduction in congestion and idleness. The result is a smoother, more constant production rate throughout, and a minimization of adjustment costs.

The group, which may consist of between two and a dozen individuals under one leader, takes care of interface problems. Sequencing problems are greatly simplified and are resolved at the lowest level. This greatly reduces fluctuations in production rate and manning. Additionally, if the budgeted resources are not sufficient to complete the work package, it is immediately apparent, and corrective action can be taken.

There are, of course, costs associated with increased productivity through the application of group technology. However, the cost savings should greatly outweigh the implementation costs. To realize the benefits, it is necessary to increase planning and control. All of the resources required for a given work package must be delivered to the work site at the right time. This entails more extensive and detailed engineering and thus a larger engineering force. A detailed classification and coding system is also required in order to realize the accuracy and cost savings made possible by the application of computers to inventory control, work scheduling and control, design, and manufacture. The next section will address some of the mechanics of adapting group technology to shipbuilding.

4. Work Breakdown Structures

Any management approach must specify what is to be done, where it is to be done, when it is to be done, and what resources are to be applied. This specification generally takes the form of division of the total process

into component parts. The system by which these components are subdivided in order to control the process is called a work breakdown structure (WBS). A work breakdown structure is a classification system. Work

breakdown structures commonly used in shipbuilding are either systems- or product-oriented. Both will be initially described in this section. The product-oriented work breakdown structure will be addressed in detail in the remaining chapters.

4.1. Systems-Oriented Work Breakdown Structure

Systems-oriented work breakdown structures are useful for initial estimates and the early design stage. They are not appropriate for planning, scheduling, and executing a zone-oriented manufacturing process. By their very nature they institutionalize the problems addressed in the previous section with work packages which are too large for effective control of material, man-hours, and schedules.

The systems-oriented structure used by the U.S. Navy will be described as an example of such a system. The Navy Ship Work Breakdown Structure (SWBS) is used throughout "... the entire ship life cycle from early design and cost studies through production and subsequent layup, including cost, weight, specifications, system function and effectiveness, design, production, and maintenance." [16] All classification groups are defined by a three-digit numeric code according to functional system. There are ten major groups, the last two of which are used primarily for cost estimating and progress reporting. The ten major groups are:

- 000. General Guidance and Administration
- 100. Hull Structure
- 200. Propulsion Plant
- 300. Electric Plant
- 400. Command and Surveillance
- 500. Auxiliary Systems
- 600. Outfit and Furnishings
- 700. Armament
- 800. Integration/Engineering
- 900. Ship Assembly and Support Services

Each major group (000, 100, 200, 300, etc.) is broken down into hierarchical subdivisions called subgroups and elements. Subgroups are those three-digit numbers ending in a single zero. All other three-digit numbers are called elements. An example of this structure is illustrated in Figure 2-11:

Briefly, the structure may be interpreted as follows:

- Groups 100 through 700 equal hardware cost and weight condition A (light ship without margin).
- Groups 100 through 700 plus 800 and 900 equal ship construction cost.
- Groups 000 plus 100 through 700 plus 800 and 900 equal total ship cost for condition A.

4.2. Product-Oriented Work Breakdown Structure (PWBS)

The U.S. Navy has used a classification system, part of which is incorporated in the SWBS described above, for over 50 years. This classification system was tailored to past design practice, where drawings and interim products were identified by system. Such a scheme is appropriate for estimating and the early design stage. However, the way that ships are actually produced is by procuring or fabricating parts and joining them to create subassemblies. In turn, these are combined through several manufacturing levels to produce increasingly larger subassemblies. Thus, the ideal way to subdivide ship construction work is to focus on needed parts and subassemblies (interim products).

A classification scheme to subdivide work in accordance with an interim product view is a product-oriented work breakdown structure (PWBS). [17] Parts and subassemblies are grouped by common permanent characteristics and classified by both design and manufacturing attributes. The classification system typically specifies parameters, such as form, dimensions, tolerances, material, and

types and complexity of machinery operations. The codes used to process data according to this classification scheme must be applicable to previously manufactured as well as current parts for the purpose of retrieving process standards. This section and Chapter III will concentrate on the classification system (PWBS) and its relationship to group technology. Coding systems and specific codes in use in the United States will be addressed in Chapter VII.

Classification by *product aspects* relates a part or subassembly to a *system* or *zone* of a ship design and also to work processes by *problem area* and by work *stage*. Thus, product families are determined both by design and manufacturing attributes. This concept, combined with a greater degree of interaction between design and production engineers, has proven to be a powerful means for improving productivity.

4.2.1. Work Package Classification. PWBS first divides the shipbuilding process into three basic types of work: *hull construction*, *outfitting*, and *painting*, because each imposes manufacturing problems that are inherently different from the others (see Figure 2-12). Zone-oriented production, i.e., the Hull Block Construction Method (HBCM), is already being applied for hull construction by most shipyards. The same logic is not employed everywhere for outfitting by zones, which is more complex and difficult to undertake.

These three types of work are further subdivided into *fabrication* and *assembly* classifications which are normally associated only with hull construction and outfitting. Within the painting classification, *fabrication* applies to the manufacture or preparation of paint, and *assembly* means its application. These *assembly* subdivisions are naturally linked to zones and are the basis for zone dominance in the management cycle.

Secondly, PWBS classifies interim products in accordance with their needs for resources, i.e., material, manpower, facilities, and expenses. For example, resources are classified and allocated in accordance with common parameters to different structural panels, regardless of their location in the ship. Different outfit units are treated the same way. Definitions of the *product resources* are:

- *Material*, to be used for production, either direct or indirect, e.g., steel plate, machinery, cable, oil, etc.
- *Manpower*, to be charged to production, either direct or indirect, e.g., welder, gas cutter, fitter, finisher, rigger, material arranger, transporter, etc.
- *Facilities*, to be applied to production, either direct or indirect, e.g., buildings, docks, machinery, equipment, tools, etc.

In order to optimize productivity, a ship must be constructed in accordance with a carefully established plan that provides for processes

(Group)	100 — Hull Structure
(Element)	101 — General Arrangement — Structural Drawings
(Subgroup)	110 — Shell and Supporting Structure
(Element)	111 — Shell Plating, Surface Ship and Submarine Pressure Hull
(Element)	112 — Shell Plating, Submarine Non-Pressure Hull
(Subgroup)	120 — Hull Structural Bulkheads
(Element)	121 — Longitudinal Structural Bulkheads
	122 — Transverse Structural Bulkheads

Fig. 2-11 Example of U.S. Navy hierarchical subdivisions.

for manufacturing parts and subassemblies leading to outfit units and structural blocks within time frames that can be coordinated, and simultaneous use of each process for the requirements of different systems, even in different ships.

The third classification, by the four *product aspects*, addresses these needs because it contains essentials needed for control of production processes. Two product aspects, system and zone, are means for dividing a ship design into planned manageable parcels. Each, for example, can apply to a number of parts or to one specific assembly. Each of the latter is usually addressed by a separate work package. The other two product aspects, *problem area* and *stage*, are means for dividing the work process from material procurement to complete ship delivery. The product aspects are:

- *System*—A structural function or an operational function of a product, e.g., longitudinal bulkhead, transverse bulkhead, fire main system, mooring system, fuel oil service system, lighting system, etc.
- *Zone*—An objective of production which is any geographical division of a product, e.g., cargo hold, superstructure, engine room, etc., and their subdivisions or combinations, e.g., a structural block or outfit unit, a subassembly of either, and ultimately a part or component.
- *Problem area*—A division of the production process into similar types of work problems which can be:
 - by feature, e.g., curved vs. flat blocks, steel vs. aluminum structure, small-diameter vs. large-diameter pipe, pipe material, etc.
 - by quantity, e.g., job-by-job vs. flow lane, volume of onblock outfitting for machinery space vs. volume of on-block outfitting for other than machinery space, etc.
 - by quality, e.g., grade of workers required, grade of facilities required, etc.
 - by kind of work, e.g., marking, cutting, bending, welding, blasting, bolting, painting, testing, cleaning, etc. and

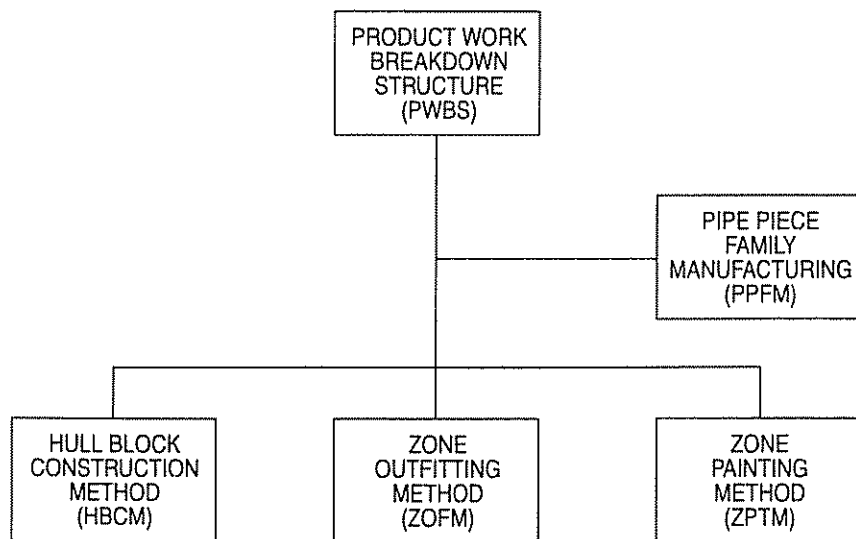


Fig. 2-12 Product work breakdown structure components

- by anything else that creates a manifestly different work problem.
- *Stage*—A division of the production process by sequences, e.g., substeps of fabrication, subassembly, assembly, erection, outfitting on-unit, outfitting on-block, and outfitting on-board.

The classification system and categories described in the foregoing subsection are illustrated in Figure 2-13.

4.2.2 Work Package Productivity Value Analysis. When an interim product is identified by product aspects, it is necessary to evaluate its efficiency as a work package which can be expressed by the formula:

$$PV = f(T, N, Q)$$

where:

- PV = productivity value, i.e., the productive efficiency of a work package
 T = time allowed for its accomplishment, i.e., working time

- N = number of units of resources, particularly components in the material list and man-hours allocated
 Q = quality of work circumstance, e.g., downhand vs overhead, high vs low, etc., and also quality specified for the interim product.

T, N, and Q are interdependent and as shown in Figure 2-14, they impact differently on PV. As they cannot be evaluated separately, it is useful to symbolize PV as a triangle having sides that represent T, N, and Q. Optimum PV is then represented by an equilateral triangle (see Figure 2-15). In other words, PV is optimized when the influences of T, N, and Q are balanced.

The function $f(T, N, Q)$ must be determined empirically by each shipyard and separately for each classification of the production process by problem area. In addition, each such determination must consider the immediate preceding and following work stages. For example, Q includes considera-

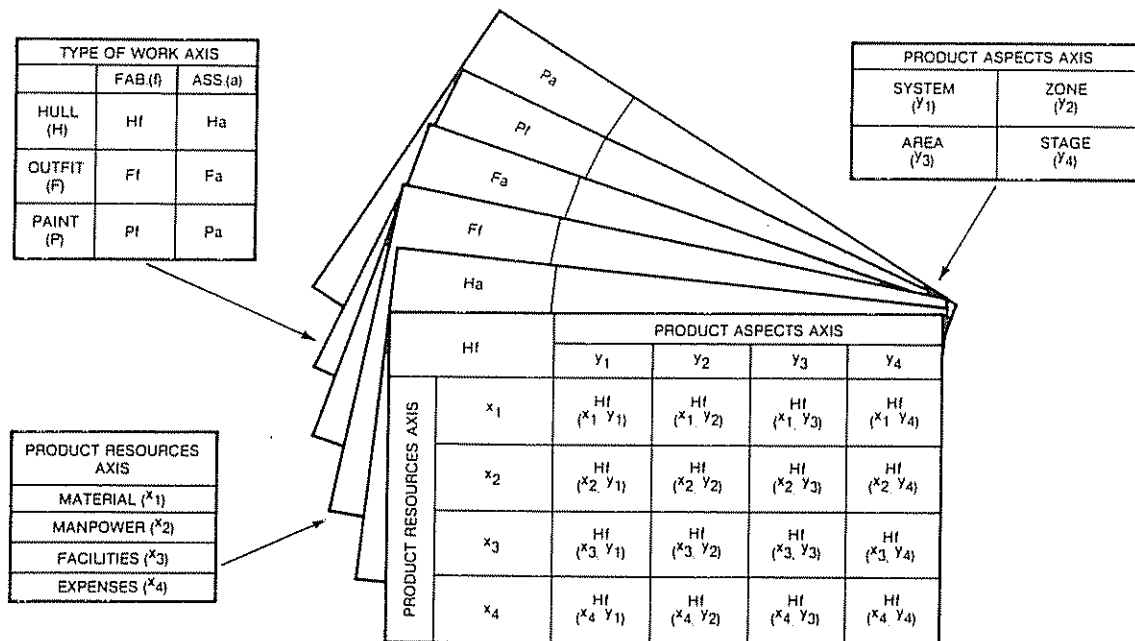


Fig. 2-13. Elements of the three-dimensional PWBS matrix.

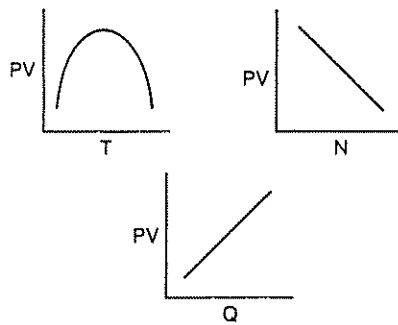


Fig. 2-14 Impacts of time, units of resources, and quality of work circumstance on productivity value.

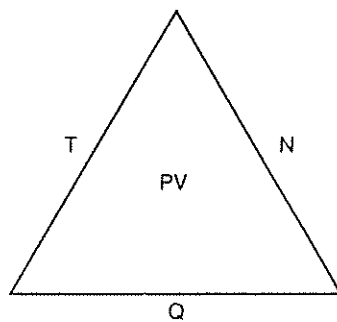


Fig. 2-15 Optimum PV requires balanced influences of T, N, and Q.

tion of the quality specified for an interim product. If its contribution to PV is not enough, the quality of the interim product is not good enough for a larger assembly.

Further, productivity values cannot be precisely determined. Therefore, they are guidance to serve a judgmental process for evaluating work packages. Their use at first involves trial and error and thereafter experience. For example, a geographical division of a product into seemingly ideal zones could yield unacceptable work packages when the needed work processes are analyzed by problem areas. Zone boundaries would then be adjusted until there is an ideal compromise

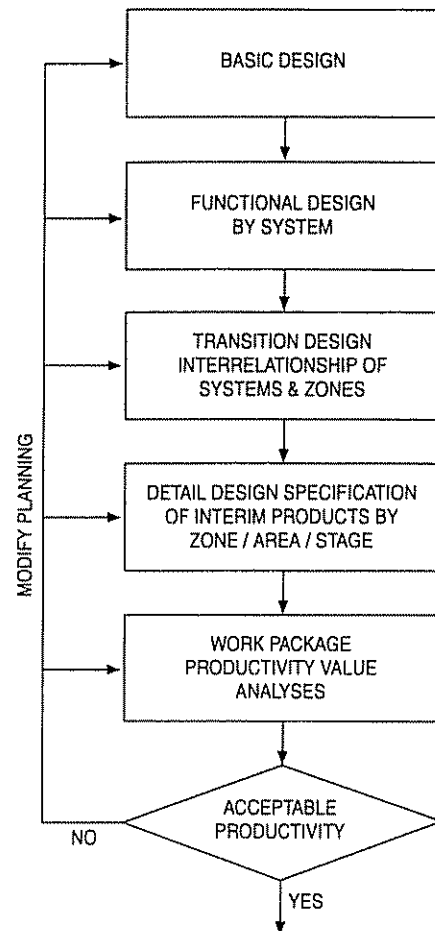


Fig. 2-16 Iterative development of work packages.

of zone and problem area considerations. Each proposed work package should be so evaluated regardless of whether it has been employed in the past. It is probable that some circumstance, especially regarding resources and time available, will have changed.

The iterative development and evaluation of work packages through the planning process is illustrated in Figure 2-16. Work packages classified by product aspects are systematically analyzed in order to determine their productivity values. The analyses may be iterative through several planning levels. The work packages are immediately updated based upon restudy following production.

Thus, work packages reflect an accumulation of experience. They are adaptable to ships of different sizes and types. Regardless of differences in functional systems, zone/problem area/stage classifications of comparable work packages for different size ships of the same type change very little. Even for different types of ships, such classifications remain essentially the same for work related to bows, sterns, engine rooms, and superstructures. Therefore, initial costs may be amortized over subsequent ship construction projects.

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PRODUCT-ORIENTED WORK BREAKDOWN STRUCTURE

1. Introduction

Major shipbuilding cost drivers, the principles of group technology by which costs can be controlled, and two classification systems (work breakdown structures) were presented in Chapter II. In this chapter the logic and procedures by which group technology (GT) is applied to shipbuilding will be introduced and the product-oriented work breakdown structure (PWBS) described in detail. The theoretical model of shipbuilding partially explained why overlap and parallelism of planning, design, material definition, material procurement, and construction of interim products are key elements in high-productivity shipbuilding. This overlap, along with highly organized planning and controlling, contributes to maintaining a level or near-level work load and to reducing idleness and congestion. Overlap is also necessary to minimize the inventory cost of work in process, and to maximize the utilization of capital equipment. The overlap of design, material definition, material procurement, and production requires that information developed in each phase be formatted according to the requirements of the other. This commonality is achieved using the product-oriented work breakdown structure (PWBS) described in this chapter.

Up to this point the generic term *group technology* has been used extensively. A par-

ticular application of group technology to shipbuilding, involving the integration of hull construction, outfitting, and painting, will be addressed in the remainder of this book. [1] The components of this integrated approach are:

- the hull block construction method (HBCM), wherein hull parts, sub-assemblies, and blocks are manufactured in accordance with the principles of group technology (family manufacturing) in organized production lines (also referred to as process lanes or work flows)
- the zone outfitting method (ZOFM), which makes possible efficiency gains, through concurrent hull construction and outfitting, by providing precise zone by stage control for which there are three basic stages: on-unit, on-block, and on-board outfitting, and a substage for downhand outfitting on overheads when blocks are upside down
- the zone painting method (ZPTM), in which surface preparation and coating are treated as an integrated aspect of the overall construction process
- family manufacturing, such as in pipe piece family manufacturing (PPFM)

- a classification system, the product-oriented work breakdown structure (PWBS), which facilitates the integration of the foregoing inherently different types of work by defining and classifying interim products (parts, subassemblies, outfit units, and blocks), which permits coordinated work flows

Integrated hull construction, outfitting, and painting affects every aspect of ship construction. It requires collaboration among all shipyard departments. Integrated planning is achieved by discussion, trade-offs, and ultimately mutual consent. The overriding goal is an increase in productivity for an entire shipbuilding system.

2. Planning for Production

Planning starts with preplanning, also called the marketing stage, and continues through design and material definition. Preplanning includes initial regulatory body review, preliminary definition of contract specifications, proportions, lines, other technical data and procurement specifications, and preliminary block definition. Preplanning will be covered in detail in Chapter VII. In order to successfully include production considerations in preplanning, a building strategy is developed. The building strategy reflects the capabilities and preferences of the shipyard, modified to fit the specifics of the vessel to be built. It is developed by considering block breakdowns, process lanes, and pallet lists and material with which the shipyard has experience, and which represent its current best practice. The building strategy helps to define and prioritize decisions about the shipbuilding project at its earliest stages. The building strategy is discussed in more detail in Chapters VI and VII. An overview of design and material definition, the importance of overlap of these stages with production, and their impact on PWBS will be treated in this section. This will be expanded in a more detailed treatment in Chapter VI.

Significant overlap of design, material procurement, and production is essential for reducing the overall construction period, but overlap reduces the time needed to organize information developed by designers. Thus, from the outset, design information must be

formatted to more fully anticipate needs relating to material and production.

In addition to overlap in time, there is an overlap between functional systems and product aspects. The work breakdown structure must allow for dual grouping. With PWBS, work packages are grouped by product aspects and cost classifications by product resources. Thus, manpower expenditures can be collected by zone/problem area/stage, while material costs can be collected by system. Figure 3-1 shows the basic management cycle of any large industrial project. The cycle includes project estimating, planning (including design and material definition), scheduling of work, executing or actually performing the work, and finally evaluating (a review of how effective each of the phases and the overall project has been). In applying PWBS, the unique nature of each of these phases in the management cycle is addressed in terms of system versus zone orientation. Since a key to shipbuilding employing PWBS is the construction of interim products, the execution stage is organized by zone. That is, the ship will be built by zone, to be joined in the final stages of construction. Consequently, efforts are made to organize support functions, such as planning, design, material definition, scheduling, and testing to match the zone orientation of construction.

Figure 3-2 indicates the primary focus, system or zone, of each of the phases in the management cycle. Note that the process begins with a systems orientation. This is a

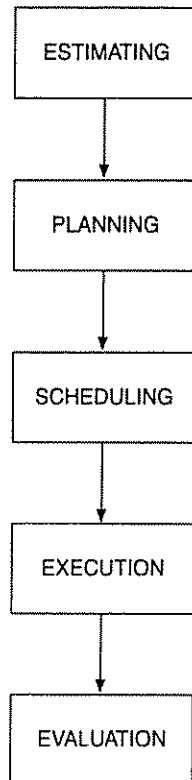


Fig. 3-1. Industrial project management cycle.

view of the total final product, the ship as a whole, broken down by systems (structural and functional). During planning (including design), a key transformation from systems orientation to zone orientation occurs. This zone orientation is then maintained through execution and some testing (a part of evaluation) to mirror the manner in which the work is performed. Finally, a transformation back to systems orientation takes place to permit overall evaluation of the product and systems testing. These system-to-zone and zone-to-system transformations are a key to group technology shipbuilding (PWBS).

2.1. Design and Material Definition

Design is divided into:

- basic design
- functional design

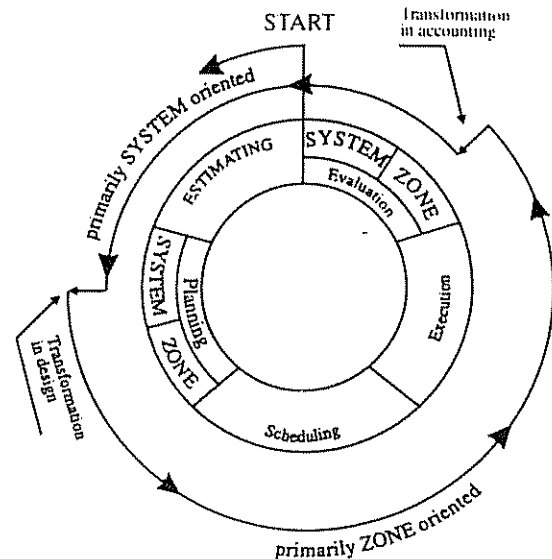


Fig. 3-2. System and zone orientations in the management cycle

- transition design
- work instruction design (detail design)

During basic design, specifications which establish performance requirements are determined. Systems diagrammatics are developed from the basic design as a part of functional design. Simultaneously, material lists divided into material-ordering zones are developed for each system diagrammatic. Other key drawings, such as general machinery and block arrangements, are prepared as a part of functional design.

During these first stages, drawings and material lists are developed by system. During basic design, products are classified by total system. Individual systems are treated in functional design. A system orientation is appropriate in the early planning stages in order to facilitate estimating and establish spatial relationships.

During transition design the work breakdown structure must accommodate a transition from system to zone groupings. Transformation to zone orientation begins with a block plan for hull construction and composite drawings for outfitting. These incorporate

all systems and show zone boundaries. They are further processed to add problem area/stage considerations during the work instruction stage. For hull construction these are designated on assembly, subassembly, and cutting plans. For outfitting, they are designated on working drawings (work instruction drawings), each of which is developed together with its own material list of fittings for on-unit, on-block, or on-board outfitting. The hierarchical subdivision continues by zone/problem area/stage with the preparation of detail design drawings for pipe pieces and components other than pipe and their respective material lists. As shown in Figure 3-3, the design process continues until each zone is broken down to components that are to be purchased and to material requirements for parts that are to be fabricated. This is the lowest hierarchical level of classification. Note that the composites shown in Figure 3-3 are used for quickly conveying arrangements and system/zone relationships to detail designers. The latter refine arrangements and designate stages during preparation of work instruction and material detail design drawings. The entire design process is discussed in more detail in Chapter VI.

Each design stage more clearly defines material requirements. Each successor stage honors commitments made and constraints imposed previously, while producing more detailed information. Most important, each successor stage transforms the developing design into a format better suited to the subsequent user's essential needs.

Design as well as production groups are organized according to classes of problems in a manner which complements planned zoning. These zones also correspond to material procurement zones. In commercial ship construction, there are typically three groups. These are:

- Hull
- Machinery
- Superstructure

Hull, machinery, and superstructure designate contiguous three-dimensional zones. In naval ship construction, additional groups, such as combat systems and nuclear propulsion systems, may be included.

Each of the above design groups prepares key drawings, working drawings, and material lists in a manner to suit initial zone designations such as those shown in Figure 3-4. Within such groups there is improved "horizontal" communication, such as that between piping and vent duct designers assigned to machinery outfitting. They become more expert about their particular class, are led away from insignificant fine tuning of systems, and instead focus on composite drawings (marked to show how a ship is to be assembled) and on structured material lists. System arrangement drawings are eliminated, and interference-free and simplified composites (drawings or scale models) are developed directly from diagrammatics. Thus design as well as production is segmented by classes of problems in accordance with the principles of group technology.

2.2 Production

Figure 3-5 shows work process lanes, organized by classes or problem areas, and how their end products must integrate for zone-oriented production. Fabrication shops and assembly sections are grouped along the various process lanes.

Hull construction has traditionally been assigned to a single production division associated with a single trade union. Therefore, the general adoption of hull block construction in process lanes similar to those illustrated in Figure 3-5 preceded zone-oriented outfitting. The outfit and integrated (hull construction and outfit) process lanes shown are quite different from those of shipbuilders who use system-oriented work packages for outfit fabrication and assembly.

For example, in a system-oriented production organization, workers are assigned to

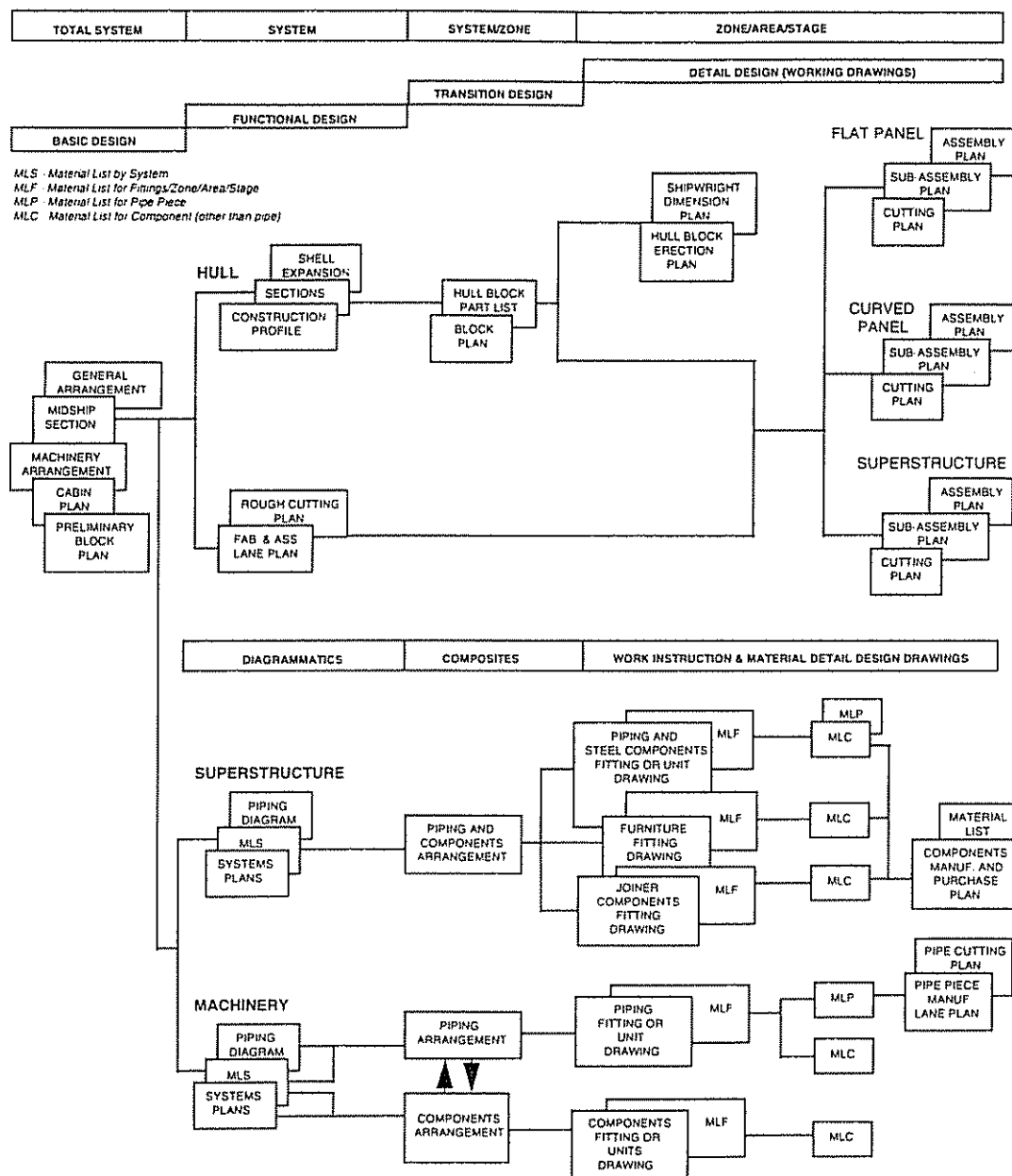


Fig. 3-3. Design process.

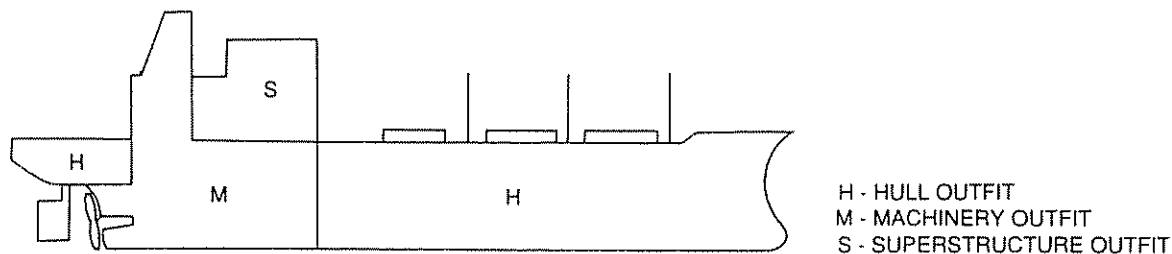


Fig. 3-4. Design outfit specialty groups.

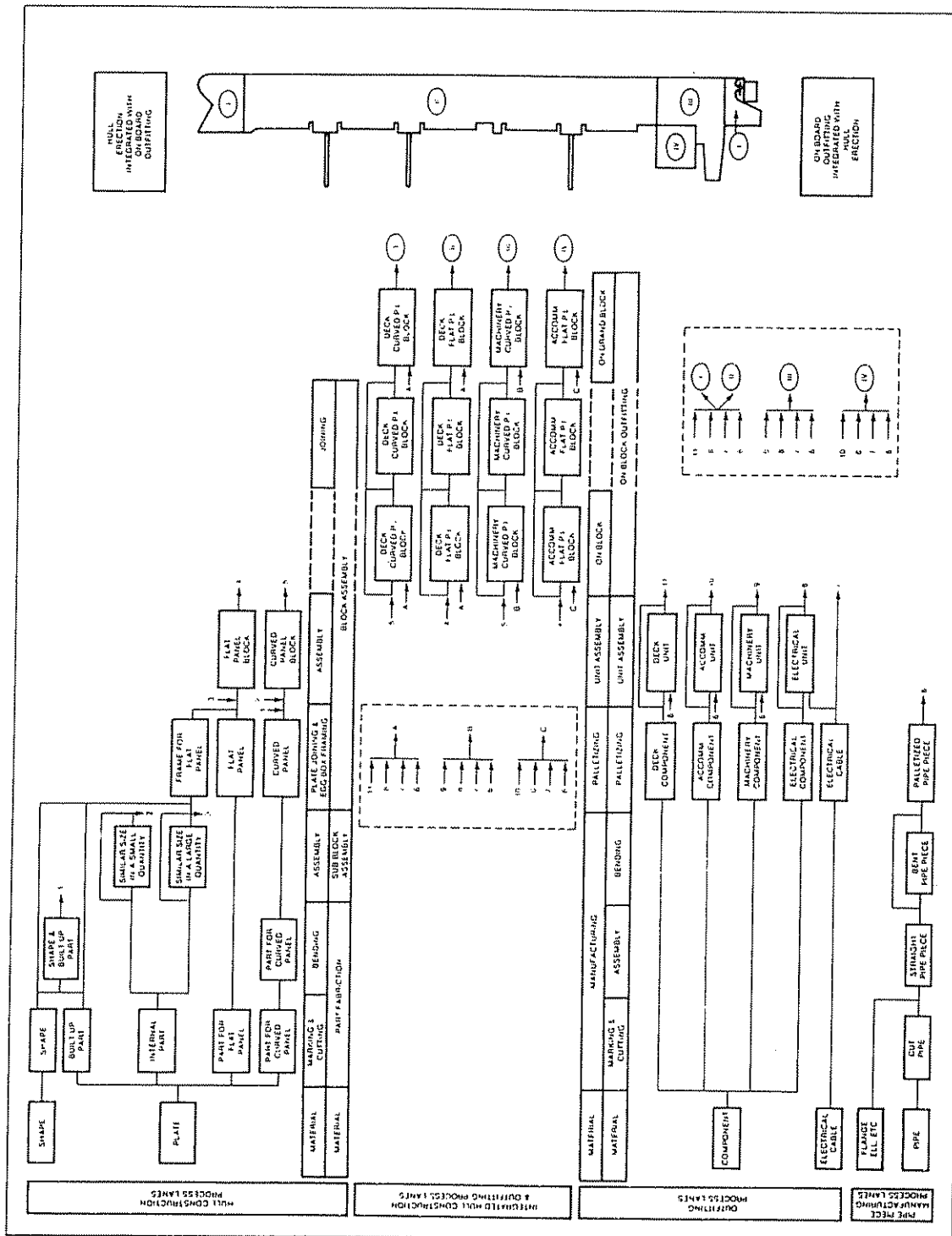


Fig. 3-5. Process lanes for simultaneous hull construction and outfitting.

a pipe shop which fabricates and assembles pieces required for all pipe systems. In a zone-oriented organization, such workers are assigned either to a fabrication shop or to a team specialized for a specific category of assembly problems. This has given rise to trades which cut across traditional jurisdictions. Workers called "assemblers" or "fitters," in addition to putting together all but high-pressure pipe, assemble everything for which a manual "stick" welder or spanner wrench suffices. This includes pipe supports, walkways, handrails, electric cable trays, etc. Other trades represented on a team are as needed for special or extensive welding, rigging, insulating, joinery, etc. In shipyards that have changed completely to zone-oriented construction, many related specialists have been combined into two: a fitter who does some welding, and a welder for special or large amounts of welding. As zone outfitting becomes more universally adopted, a logical development would be an "outfitter" trade. While such simplified trade demarca-

tions would facilitate group technology shipbuilding, traditional trade organization would not preclude the adoption of these principles.

2.3. Controlling

Zone-oriented scheduling is necessary to control the flows of work on various process lanes so that the creation of interim products anticipates only immediate needs. Such scheduling coordinates hull construction, outfitting, and painting, and allows periods after work stages for the collection and distribution of interim products to other work stations. The goal is to minimize buffer storage. Thus, integrated schedules, as shown in Figure 3-6, are essential for fabrication through final outfitting. The schedules should address all fabrication and assembly work, including lofting and painting.

A primary end product of schedules is flexibility, the ability to quickly identify good options based upon constant feedback about material procurement and work progress. Adjustments are needed to counter potential

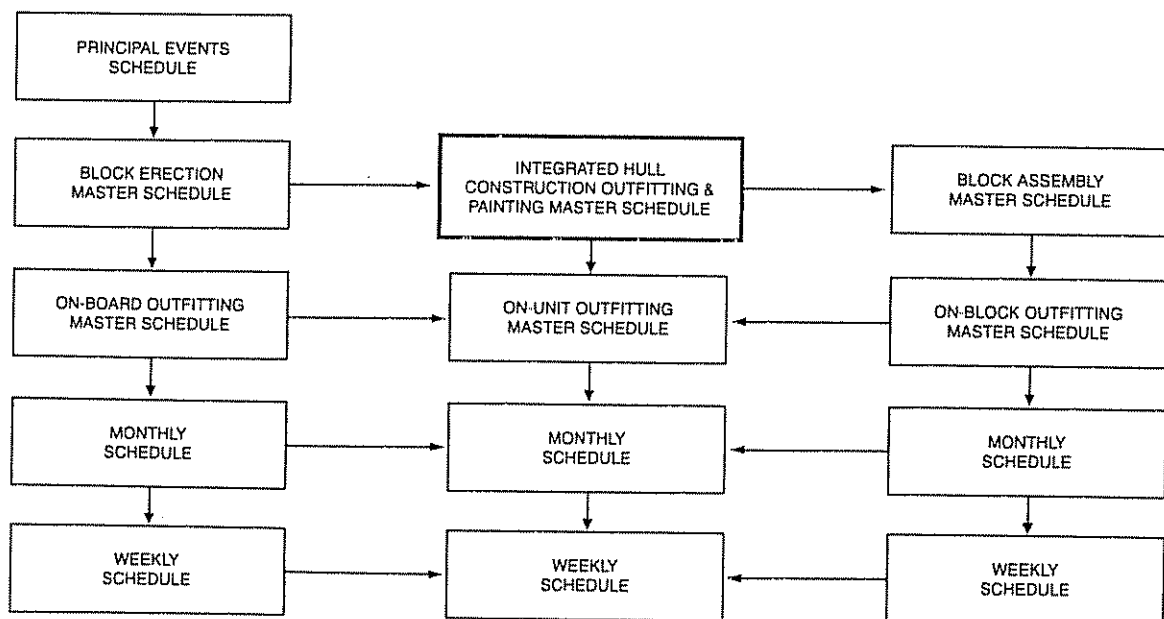


Fig 3-6 Integrated schedules for hull construction, outfitting, and painting

delays and early completions. Adjustments could include transfer of workers between process lanes, the use of overtime, or short-term schedule changes. The objectives are to maintain uniform work flow within each process lane and coordinated outputs from all process lanes.

Feedback implies accurate progress reporting of manpower and material costs by zone/problem area/stage. Accurate progress reporting is facilitated by relatively small, uniform work packages. Small, uniform work packages lend objectivity to progress reporting; a work package is either completed or it isn't. The problems cited in Chapter II of borrowing man-hour budgets, and of losing track of man-hours because of the long time that a work package is open, are eliminated. This also brings work packages into congruence, time-wise, with the most detailed (weekly) schedules.

2.4. Costing

Zone orientation introduced the concept of control linked to many relatively small amounts of material grouped by zone/problem area/stage. Progress reporting and cost collections are zone-oriented, so that managers have tangible means of corroborating work completed in order to forecast work remaining and resources required for completion. In order to serve estimators, manpower costs by system have to be rationalized. Certain indices, described in Chapter VII, are needed for distribution of spent man-hours to systems.

The indirect collection of costs by system may seem to be a degradation of feedback to estimators. However, while collecting costs

by a zone-oriented method and applying them to systems in accordance with estimated distributions is less precise, it produces more accurate data due to inherently better control. Because of the multiple character of a PWBS, material usage is easily collected both by system and zone. Where functional designers are required to identify all materials for each system diagrammatic, there is a quick corroboration of the material estimate. If a catastrophic error is disclosed, there is time for remedial measures before the major procurement effort begins.

Additionally, when functional designers are required to divide each material list by system into lists of material required for various material ordering zones, it is possible to quickly corroborate estimated manpower requirements. This is feasible when the system/zone transformation indices are based upon material, such as man-hours-per-hundred-weight of fittings, man-hours-per-foot of electric cable, etc. Where these techniques are applied, the rapid feedback to estimators is of sufficient accuracy for immediate use in preparing another estimate.

All material requirements are listed by system for purchasing and subsequently on structured (zone-oriented) material lists for issue purposes. Therefore, the interrelationships maintained by designers permit material progressing by zone to be accurately converted to material progressing by system if a customer so desires. Similarly, the system/zone transformation indices could serve a customer's requirement to progress manpower by system.

3. Zone Construction Method

Because inherently different types of work are required, a product-oriented breakdown of ship construction work should accommodate the following zone-oriented methods:

- hull block construction method (HBCM)
- zone outfitting method (ZOFM)
- zone painting method (ZPTM)

Also, because large quantities and varieties of pipe pieces, ventilation ducting, structurals, etc., are needed, the work breakdown should accommodate problem area-oriented family manufacturing (FM).

Work packages are ideally sized for the three zone-oriented methods when, for each process lane, their required working times for all manufacturing levels are the same, and, within each manufacturing level, their work contents are the same. Compliance with these conditions permits each process lane to be operated like an assembly line where work starts, flows, and stops in unison. In order to balance work accordingly, special manufacturing levels outside the main flow are needed to adjust work amounts and to provide for interim product features that would otherwise be disruptive.

3.1. Hull Block Construction Method (HBCM)

Optimum blocks (zones) are key objectives as the basis for control in HBCM. But blocks also impact on zone outfitting and painting. Therefore, the definition of blocks, compared to other interim products, has the greatest influence on shipbuilding productivity. Blocks should be designed so that:

- for block assembly purposes, they are assignable to one of a minimum number of work package groups, considering similarities in problem area and the need to minimize variations in working times
- for block erection purposes, they will be stable configurations requiring no temporary support or reinforcement and otherwise shaped to achieve minimum working times
- for on-block outfitting and painting, they are sized for maximum accessibility (maximum area and/or volume)

Also, there should be similarities in volume, weight, shape, etc., even at the expense of design convenience, to distribute work evenly

throughout the fabrication and assembly levels which precede block assembly. Thus, planners have to keep in mind that breaking down the work leading to block assembly requires shifting welding from difficult to downhand positions to reduce the working times needed, and distributing much work traditionally performed during block assembly among earlier levels to equalize their working times. Chapter VI provides additional discussion of the formulation of a block breakdown for a new ship construction project.

For large ships, blocks planned in accordance with the foregoing should also be of the largest size permitted by facilities. The same planning applied to a smaller ship of the same basic type quickly achieves nearly the same work balance with the same game plan. This is an important competitive advantage. However, pertinent work package contents, working times, and interim product sizes become smaller. Thus, there is sometimes need for an additional manufacturing level for joining blocks into grand blocks.

With regard to this objective, it is practical to plan hull construction in seven levels as shown in Figure 3-7. Starting with the block level, work is subdivided down to the parts fabrication level to optimize work flow. In contrast, work assigned to the grand block level serves to minimize the duration required for erection in a building dock. The main work flow path, or process lane, follows the arrows on Figure 3-7. For maximum productivity, this main work flow must be level.

Within each level other than the grand block and hull erection levels, the resulting proposed interim products are examined for similarities in their product aspects. Then they are grouped by similarities in order to:

- further modularize the production processes
- justify expensive but highly efficient facilities
- achieve manpower savings

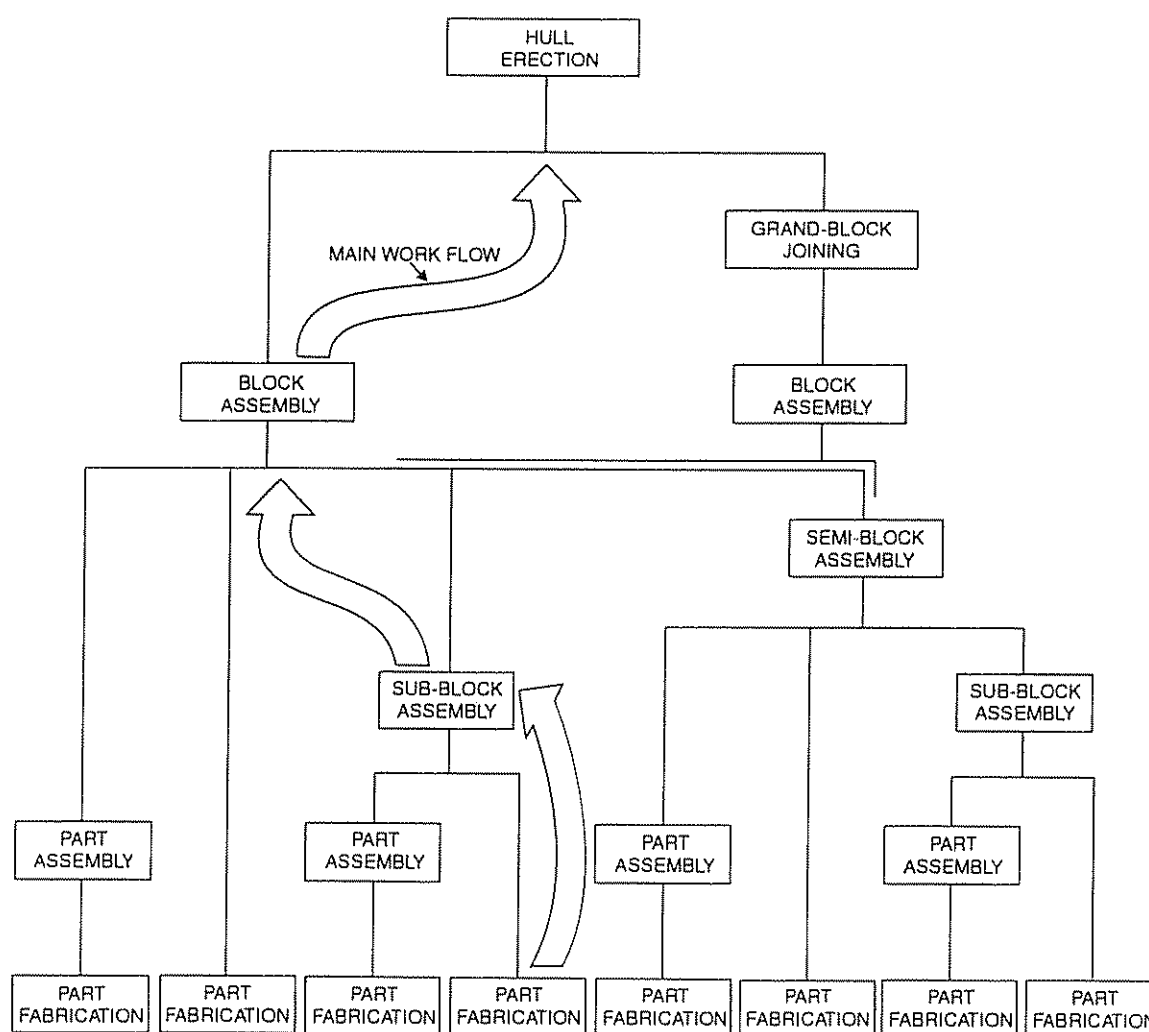


Fig 3-7. Hull block construction method (HBCM) manufacturing levels

Typical groupings by product aspects are presented in Figure 3-8. The horizontal combinations characterize the various types of work packages that are requisite and sufficient for the work to be performed for each level. Vertical combinations of the various types of work packages denote the process lanes for hull construction work flow which correspond to those simply illustrated in Figure 3-5.

When product resources are allocated, each work package is optimally sized, based

on determination of its productivity value (PV). Some reiteration can be expected, because grouping by problem area at each level is dependent upon the productivity values achievable. Maximum productivity is obtained when work is evenly allocated to work packages grouped by their product aspects, and there are quick responses to potential work imbalance, such as shifting workers between manufacturing levels and/or flow lanes, authorizing overtime, or even making astute short-term schedule changes.

3.1.1. *Parts Fabrication.* As shown in Figure 3-8, parts fabrication is the first manufacturing level. It produces components or zones for hull construction which cannot be further subdivided. Work packages are grouped by zone, problem area, and stage. Distinct problem areas based on differences in raw materials, finished parts, fabrication processes, and relevant facilities are:

- parallel parts from plate
- nonparallel parts from plate
- internal parts from plate
- parts from rolled shapes
- other parts, such as parts from pipe

Stage is determined by grouping similarities in part types and sizes, as follows:

- plate joining or nil
- marking and cutting
- bending or nil

"Nil" indicates that no product aspect exists; therefore it is left blank in categorization and coding and is skipped in process flow.

For large quantities of parts to be bent, problem area can be subdivided by the resources available, such as:

- universal press (single-axis shallow curvature)
- press with die (small parts, such as bracket flange)
- mechanized line heating (double-axis shallow curvature)
- manual line heating (double-axis deep curvature and correction of any part)

A faceplate, for example, is marked and nested on a plate with other such parts that can be cut in one pass by a multiflame planer. Those which require different curvatures are then grouped together, provided they can be processed by a press without the need to change dies. Faceplates, including those that are to remain straight, are then grouped by

block and distributed to succeeding work packages. Typical groupings of work packages for parts fabrication are illustrated in Figure 3-9. Each part shown corresponds to a hull construction zone which cannot be subdivided.

3.1.2. *Part Assembly.* The second manufacturing level is special and outside the main work flow. Its typical work packages are grouped by problem area as:

- built-up part (such as tee- or el-section longitudinals of large or unusual sections not rolled by mills)
- sub-block part (such as a part which is a weldment, typically consisting of a bracket fitted with a faceplate or flat bar, as shown in Figure 3-10)

The sub-block "part" concept is a planning technique for shifting work from the sub-block assembly level, where excessive work volume is otherwise probable, to an earlier level outside the main work flow. Undertaken with simple facilities as compared to those required for sub-block assembly, such as mechanized conveyors, manufacturing sub-block "parts" in the part assembly level is a means of balancing work and conserving resources. Further, as such "parts" are only used in sub-blocks, zone identification employs the same code as for sub-blocks (see Figure 3-8). Stage is divided into:

- assembly
- bending or nil

3.1.3. *Sub-block Assembly.* Sub-block assembly appears in the third manufacturing level of Figures 3-7 and 3-8. A zone is generally a weldment, consisting of a number of fabricated and/or assembled parts, which will eventually be fitted on a panel during block assembly. Typical work packages are grouped by problem area for:

PLAN'G LEVEL	MFG LEVEL	PRODUCT ASPECTS										CODES		
		ZONE	AREA					STAGE		ZONE	AREA	STAGE		
1	7	SHIP	FORE HULL	CARGO HOLD	ENGINE ROOM	AFT HULL	SUPERSTRUCTURE	TEST		SHIP NO.	BLOCK CODE	STAGE CODE		
								ERECTION						
2	6	BLOCK	NIL	FLAT PANEL	CURVED PANEL	SUPERSTRUCTURE	BACK PRE-ERECTION	NIL	GRAND BLOCK CODE	GRAND-BLOCK CODE	STAGE CODE			
							PRE-ERECTION	NIL						
							JOINING	NIL						
3	5			FLAT	SPECIAL FLAT	CURVED	SPECIAL CURVED	SUPERSTRUCTURE	BACK ASSEMBLY	NIL	BLOCK CODE	BLOCK CODE	STAGE CODE	
									ASSEMBLY					
									FRAMING	NIL				
			PLATE JOINING						NIL					
4	4		SIMILAR SIZE IN A LARGE QUANTITY	SIMILAR SIZE IN A SMALL QUANTITY	BACK ASSEMBLY		NIL	SEMI-BLOCK CODE	SEMI-BLOCK CODE	STAGE CODE				
					ASSEMBLY									
					PLATE JOINING	NIL								
5	3				BACK ASSEMBLY		NIL				SUB-BLOCK CODE	SUB-BLOCK CODE	STAGE CODE	
					ASSEMBLY									
		ASSEMBLY												
6	2	SUB-BLOCK PART	BUILT-UP PART	BENDING	NIL	ASSEMBLED PART CODE	STAGE CODE							
				ASSEMBLY										
7	1	PART	PARALLEL PART FROM PLATE	NON-PARALLEL PART FROM PLATE	INTERNAL PART FROM PLATE	PART FROM ROLLED SHAPE	OTHER	BENDING	NIL	PART CODE	PART CODE	STAGE CODE		
								MARKING & CUTTING						
								PLATE JOINING	NIL					

Fig 3-8. HBCM classification by product aspects.

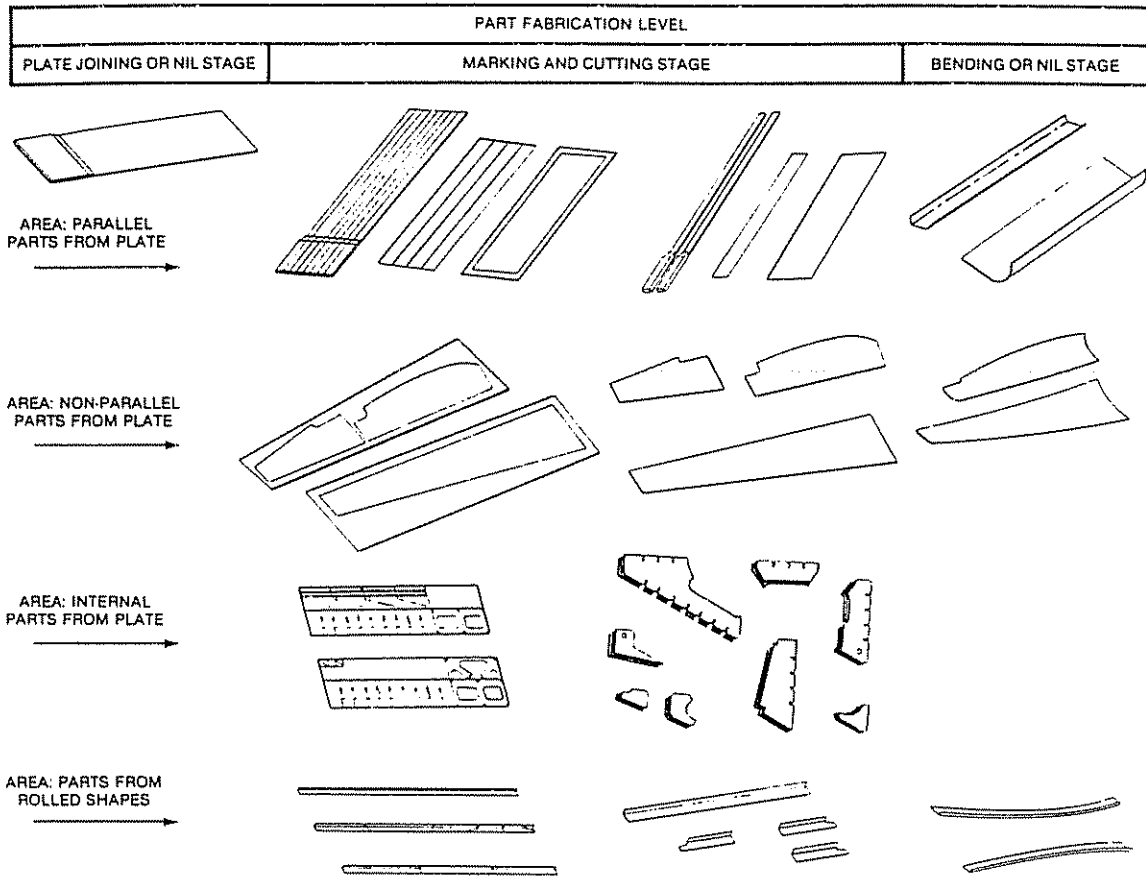


Fig. 3-9 Parts fabrication problem area and stage classifications.

- similar size in large quantities, such as large transverse frames, girders, floors, etc.
- similar size in small quantities

Subassemblies falling within the first problem area regardless of their design differences can be mass produced size by size on process lanes with appropriate facilities, such as conveyors. Those in the second category require a job-shop approach because of insufficient numbers for any one size, and different working times required for the different sizes that are normally encountered. Stage classifications are:

- assembly
- back assembly or nil

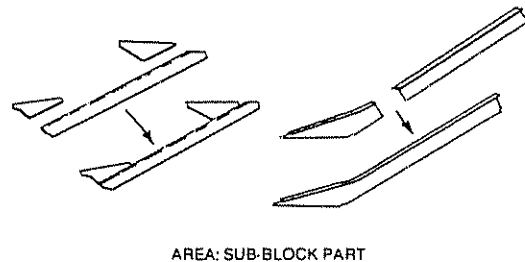
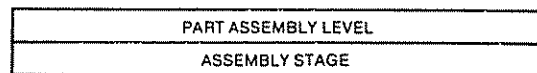


Fig. 3-10 Part assembly level classification.

During back assembly, parts and/or assembled parts are fitted on the opposite side of a marked surface of a main part (back assem-

bly is additional fitting after overturning). Examples are shown in Figure 3-11.

3.1.4. Semi-block and Block Assembly and Grand-block Joining. A block is the key zone for hull construction as indicated in Figures 3-7 and 3-8. It may, depending on circumstances, be planned in three assembly levels:

- semi-block assembly
- block assembly
- grand-block joining

Only block assembly is in the main work flow. The other levels provide useful planning alternatives. All are planned in accordance with the concept of grouping work packages by problem area and stage.

A semi-block serves the need to assemble a partial zone separate from a key zone (block) whenever a block would otherwise disrupt work flow. When a semi-block is employed, the block assembly level is where it joins its "mother" block, which was processed in the main work flow.

Grand-block joining (combining a number of blocks to create a larger block at a site near a building dock) reduces the working time needed for erection in a building dock, produces a shape that is more stable for erection purposes, and provides greater area and volume, which facilitates further on-block out-fitting and painting. The grand-block level,

which is outside the main flow, is needed in order to quickly achieve a nearly uniform work balance when zone divisions from a large ship are applied to a small ship. The ensuing smaller size blocks are joined into grand-blocks to minimize the working time needed in a building dock for erection. The zone of semi-block and block assembly, and grand-block joining ranges from block to ship, as shown in Figure 3-8.

The semi-block assembly level is divided by problem area in the same manner as for the sub-block level. Most semi-blocks are rather small in size and two-dimensional, so that they can be produced in a sub-block assembly facility. In planning work, this should be the point of divergence for separating semi-block assembly from block assembly. The grouping for stage for semi-blocks is also the same as for sub-blocks, as also shown in Figure 3-8.

The block assembly level is divided by problem area using distinguishing features of the panel needed as a base for attaching parts, assembled parts, and/or sub-blocks, and uniformity of required working times. These characteristics determine whether platens or pin jigs are required, or blocks are to be assembled in a flow where work starts and completes in unison. Because of their uniqueness, superstructure blocks are addressed separately. Pertinent problem area divisions and necessary definitions are:

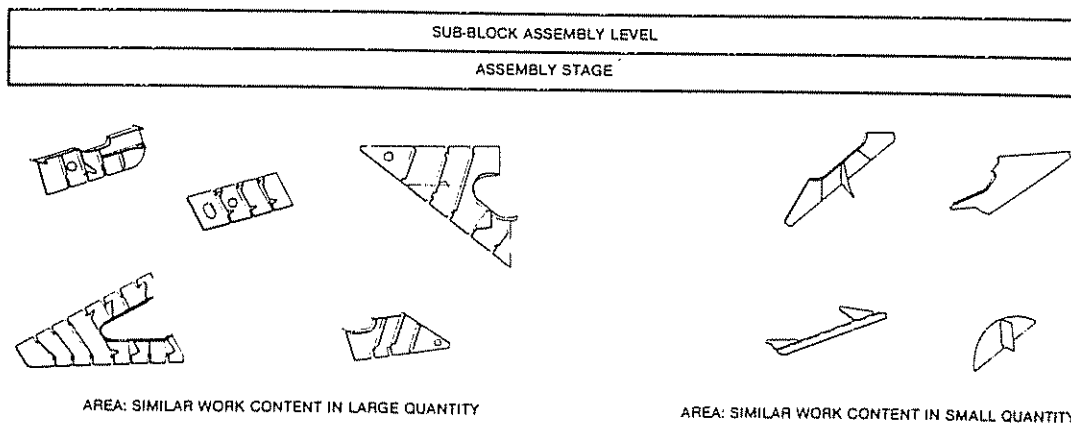


Fig. 3-11. Sub-block assembly level examples

- flat (working time is uniform and there are no projections from panel undersides which require special jigs or which would interfere with platens equipped with conveyors)
- special flat (working time is non-uniform and/or unique jigs or supports are needed)
- curved (working time is uniform)
- special curved (working time is non-uniform and/or unique jigs or supports are needed)
- superstructure

Because of variations in working times and/or jigs, special flat and special curved blocks are not assembled in facilities designed for work flow where starts and completions are in unison. Thus, they require a job-shop approach.

If the quantity of blocks to be produced is small, less than five problem area classifications should be considered. Typical classifications by problem area are illustrated in Figure 3-12.

As shown in Figure 3-8, the block assembly level is phased by stage as follows:

- plate joining or nil
- framing or nil
- assembly
- back assembly or nil

The assembly stage at the block level is for combining a panel with parts, assembled parts, and/or sub-blocks, and sometimes a semi-block. When many blocks are required it could be useful to add further classifications by problem area, based upon internal framing, such as:

- egg box
- longitudinals attached before webs
- longitudinals attached after webs
- other

At the grand-block joining level, only three classifications by problem area are normally required:

- flat panel
- curved panel
- superstructure

Stage at this level is subdivided into:

- joining or nil
- pre-erection or nil
- back pre-erection or nil

For very small ships, the pre-erection stage provides for joining grand blocks in order to create grand-grand blocks. Back pre-erection provides for further assembly work after turnover, such as attaching bulwarks, chain pipes, etc. Figures 3-13 through 3-23 show relationships between semi-blocks, blocks, and grand blocks that were actually employed for construction of a 22,000 dwt general cargo carrier. It was purposely selected as the basis for illustration because it is one of a kind, rather than a ship of a standard series.

3.1.5. Hull Erection. Erection is the final level of hull construction where the entire hull is the zone. Problem areas at this level are:

- fore hull
- cargo hold
- engine room
- aft hull
- superstructure

Stage is simply divided into:

- erection
- test

Tests at this level, such as tank tests, are independent of erection and are distinguished by the size of their work packages as compared with the tests and inspections of other levels. The latter tests and inspections are included in the packages of each level and respectively implemented at the time when each interim product is being finished.

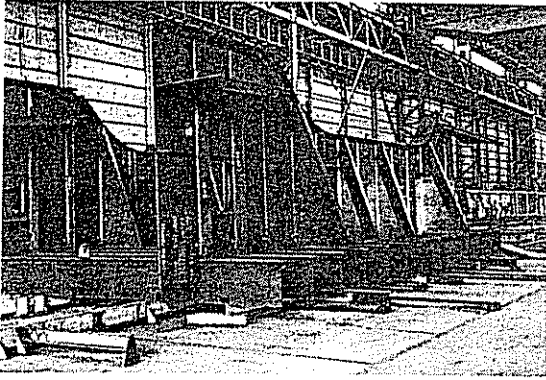


Fig. 3-12(a)

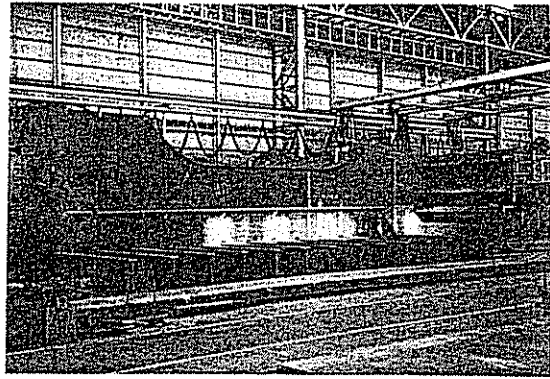


Fig. 3-12(b)

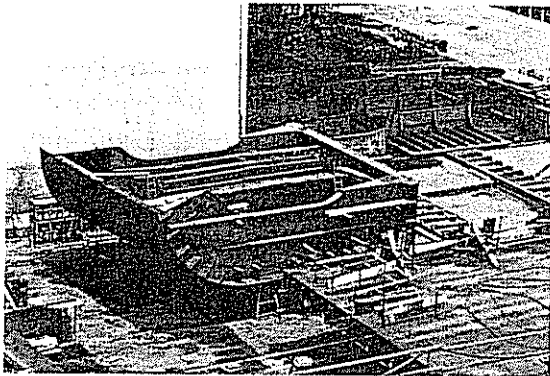


Fig. 3-12(c)

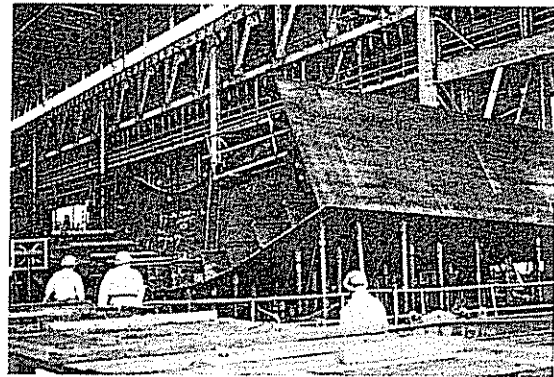


Fig. 3-12(d)

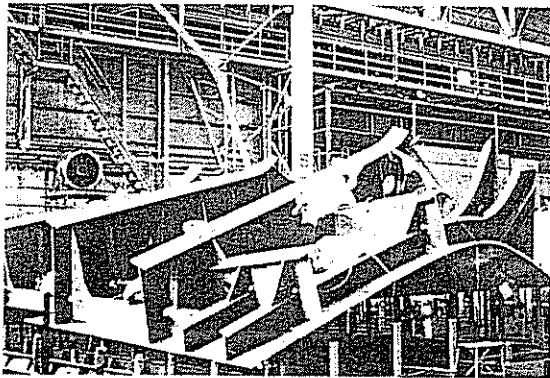


Fig. 3-12(e)

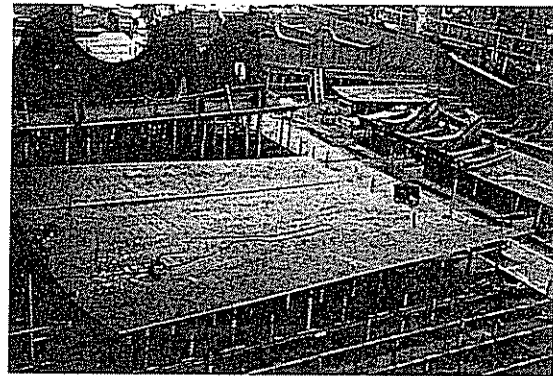


Fig. 3-12(f)

Fig. 3-12. Block assembly problem area and stage classifications (a) Problem area: flat; stage: egg box framing (b) Problem area: flat; stage: assembly (c) Problem area: special flat (greater work content); stage: assembly off flow (d) Problem area: curved; stage: assembly (e) Problem area: special curved (greater work content); stage: assembly off flow (f) Problem area: curved and special curved; stage: assembly on and off flow.

3.2. Zone Outfitting Method

The zone outfitting method (ZOFM) is a natural consequence of the hull block construction method (HBCM), because both employ the same logic. Shipyards which employ ZOFM assemble most outfit components independent of or on hull blocks.

Just as for hull construction, zone divisions from a similar previously built ship are tailored to fit a new contract design. The coded significance in work package numbers remains essentially unchanged. Thus, everyone involved in design, material definition, procurement, parts fabrication, and assembly has knowledge of how outfitting is to progress.

3.2.1. Zone by Problem Area by Stage. HBCM planners define interim products starting with a hull as a zone, then subdivide it into block zones which in turn are divided into sub-block zones and so on. The process is completed when zones correspond to parts and

cannot be further subdivided. The nature of any of these zones associates it with a specific manufacturing level. This breakdown is natural for hull construction but not for outfitting.

ZOFM planners have to consider block zones for hull construction. Elsewhere, they should be free to devise zones which best suit the work at hand. Their outfit zones at one manufacturing level can be independent of zones in previous or succeeding levels. For example, in hull construction, zone sizes increase as manufacturing progresses. On the other hand, for control purposes, outfitting zones at earlier stages could be larger and have no common boundaries with zones defined for subsequent stages. Overlapping zones are of no consequence provided they are designated for different stages. Thus, while there is greater freedom in defining outfit zones, specifying zone by problem area by stage affords absolute control of work even in a confined region that contains portions of many systems. Outfitting work packages cor-

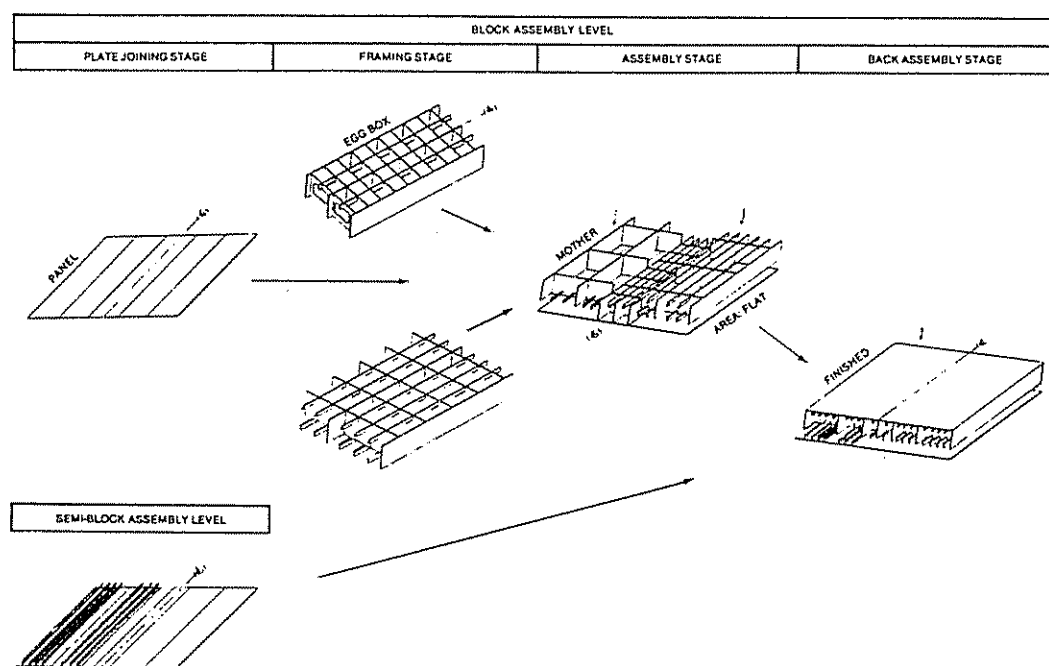


Fig 3-13 Semi-block and block assembly, showing the bottom center block of a cargo hold.

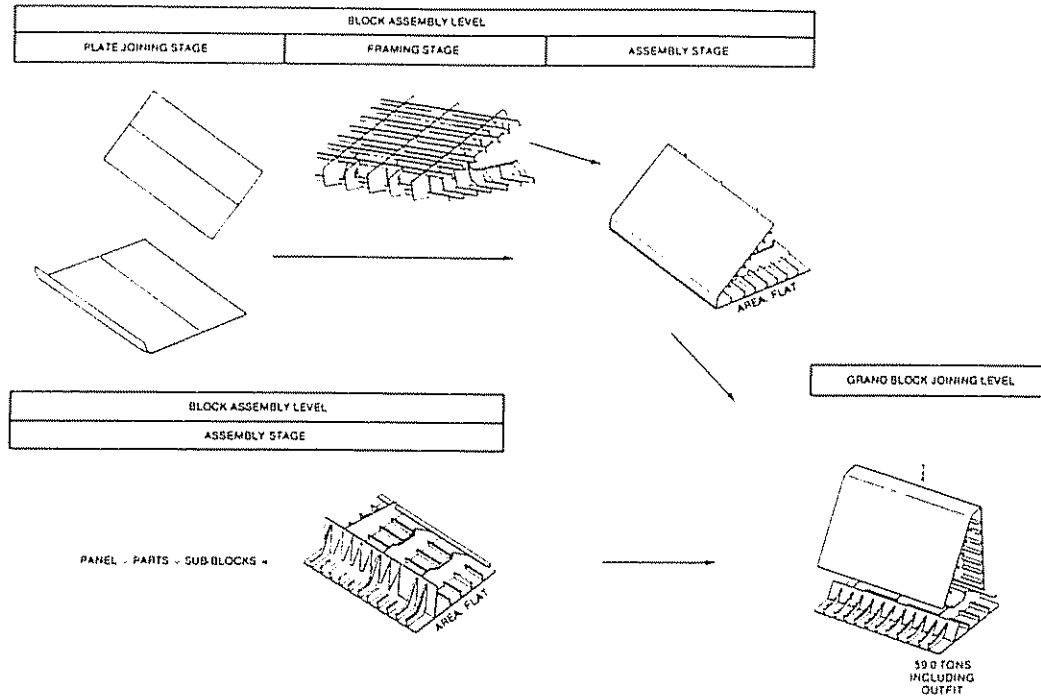


Fig 3-14 Block assembly and grand-block joining, showing the top of a wing tank

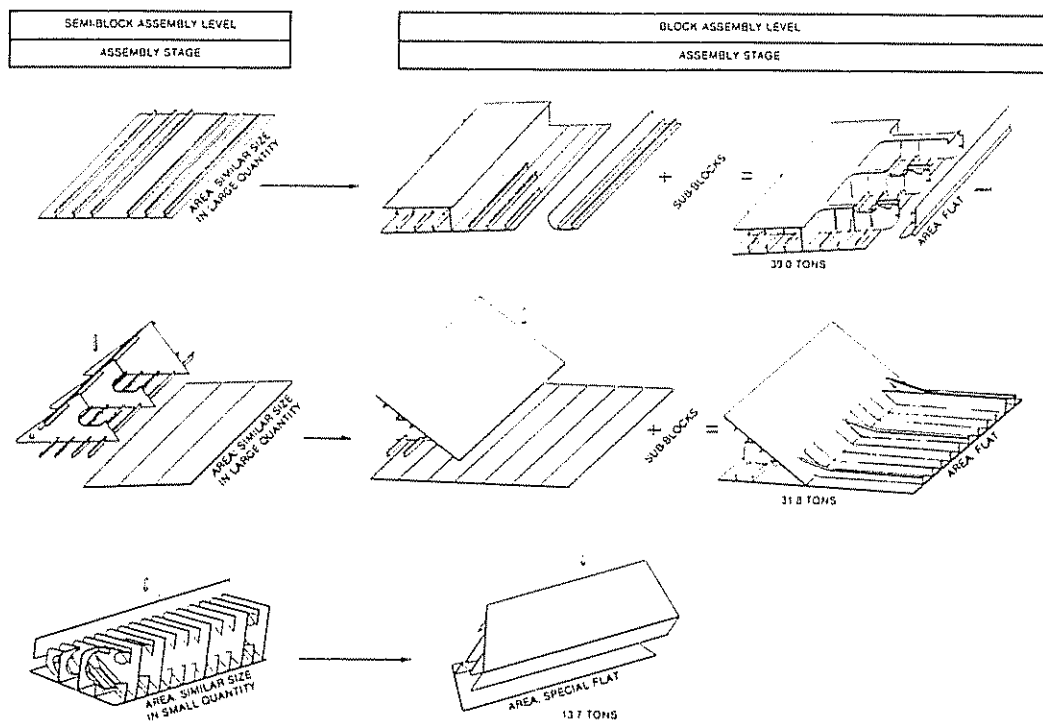


Fig 3-15 Semi-block and block assembly, showing a bottom wing tank side shell with hopper and the transverse hopper in a cargo hold

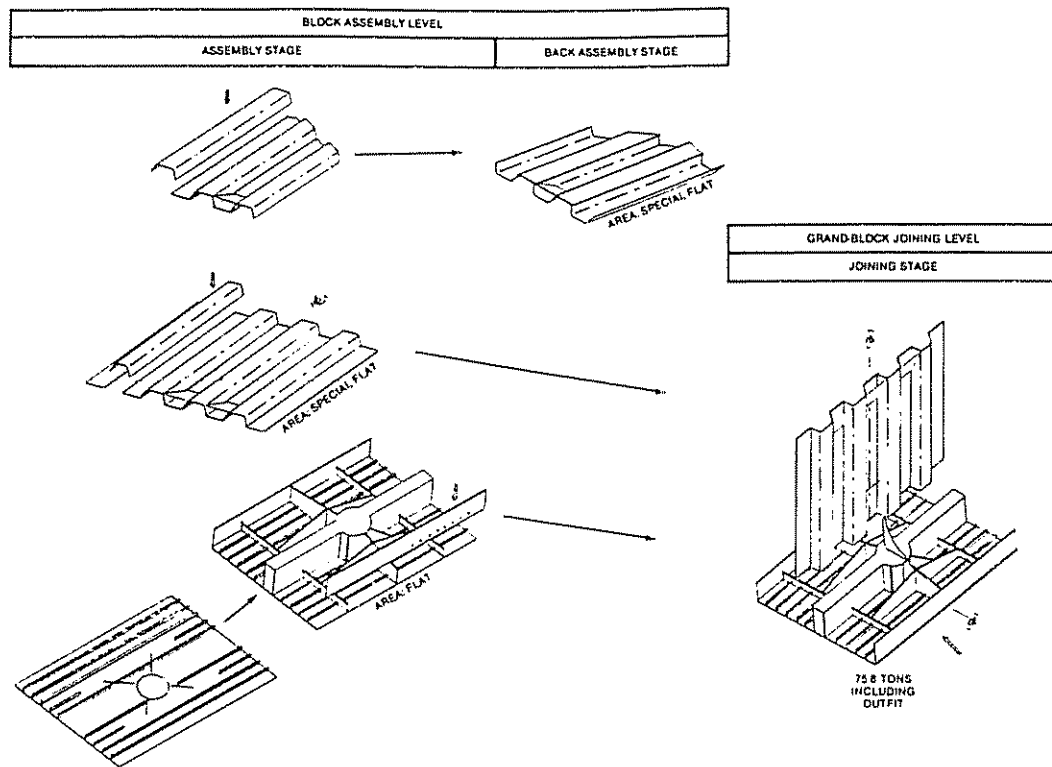


Fig 3-16 Block assembly and grand-block joining, showing a corrugated transverse bulkhead and a deck center between cargo holds

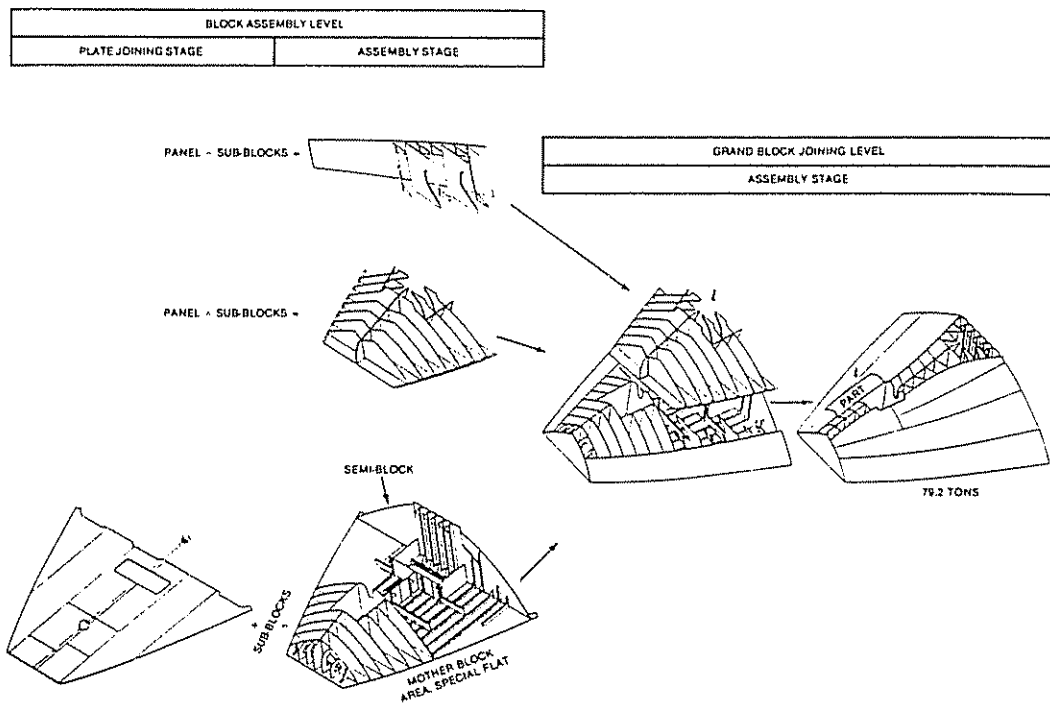


Fig 3-17. Block assembly and grand-block joining, showing a cant block

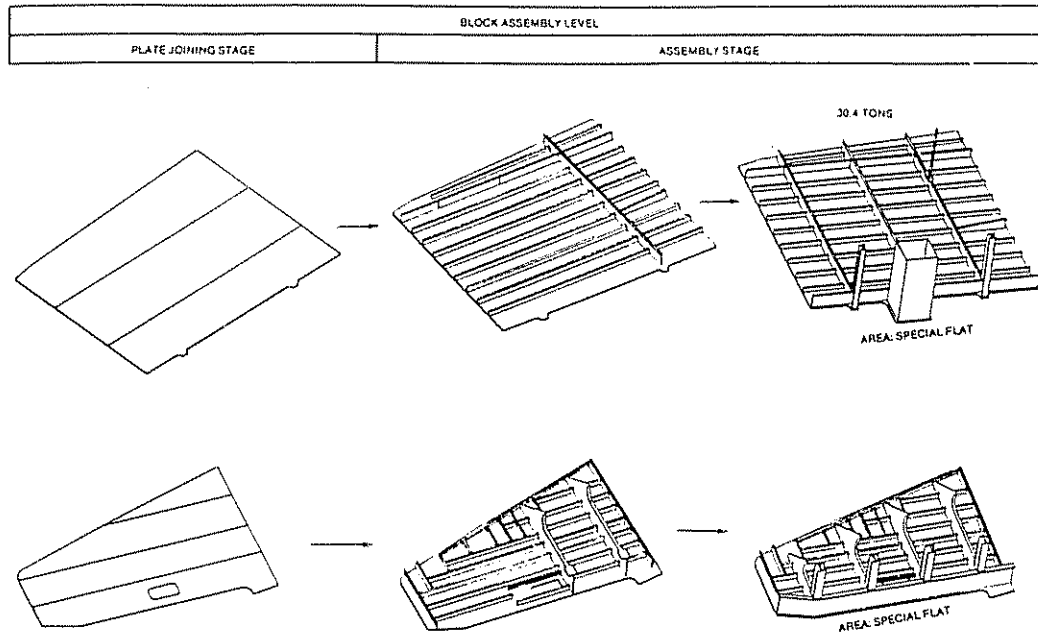


Fig 3-18. Block assembly, showing an upper deck and an engine room flat

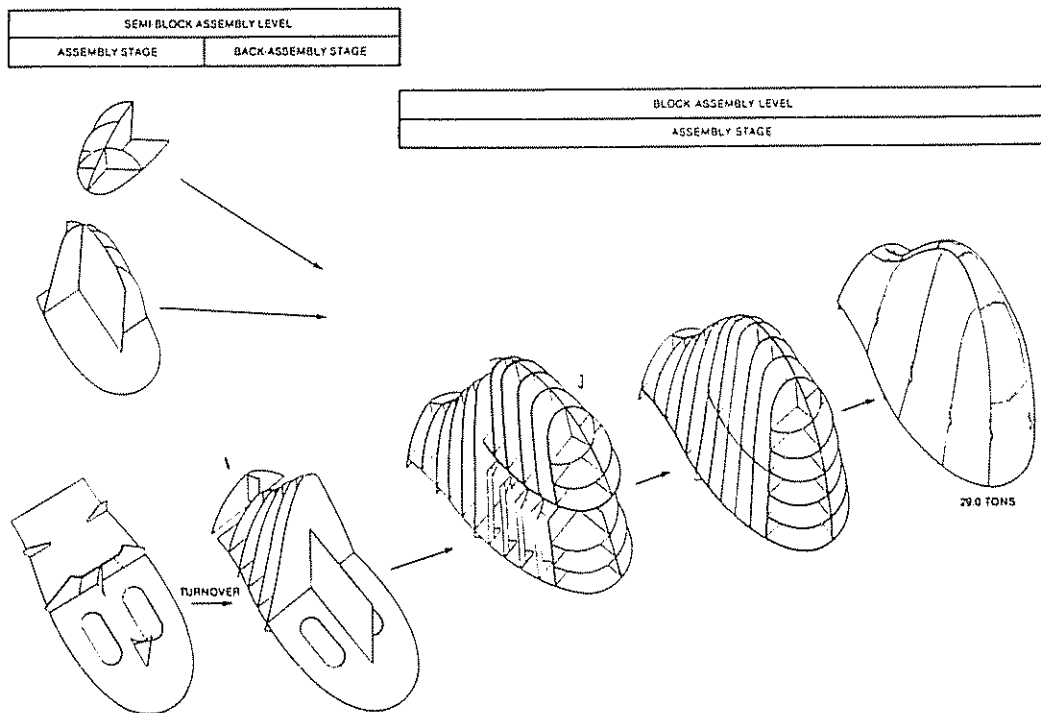


Fig. 3-19. Semi-block and block assembly, showing a bulbous bow

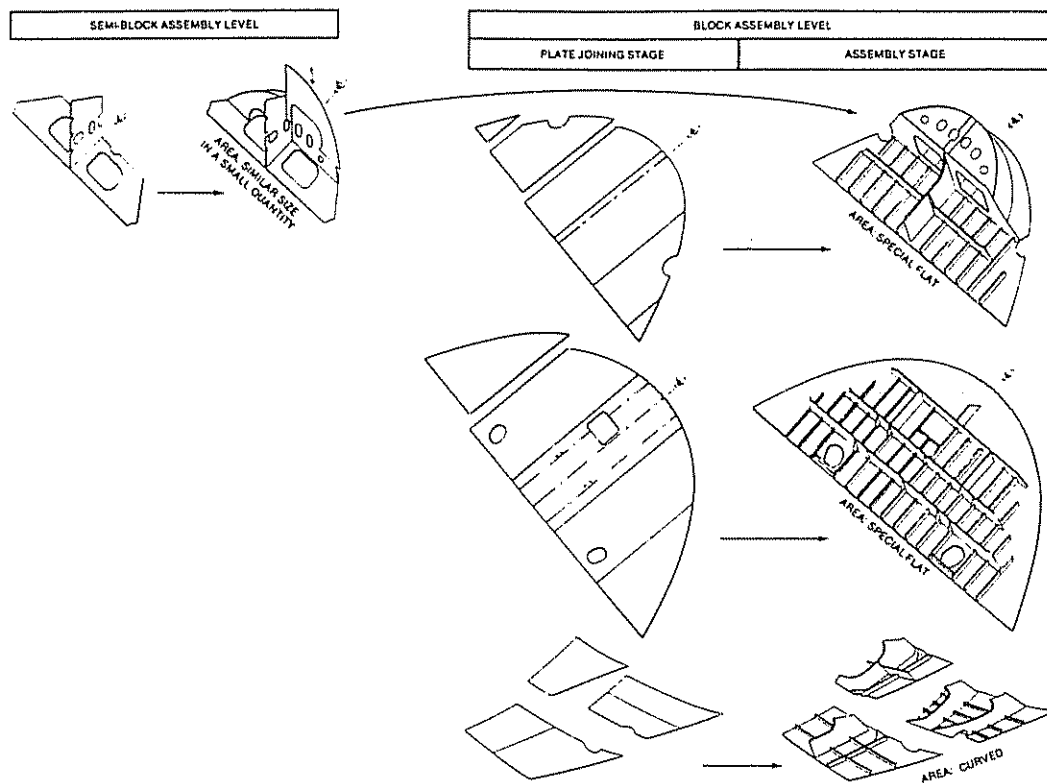


Fig. 3-20. Semi-block and block assembly, showing a forecastle and the upper deck in a fore body.

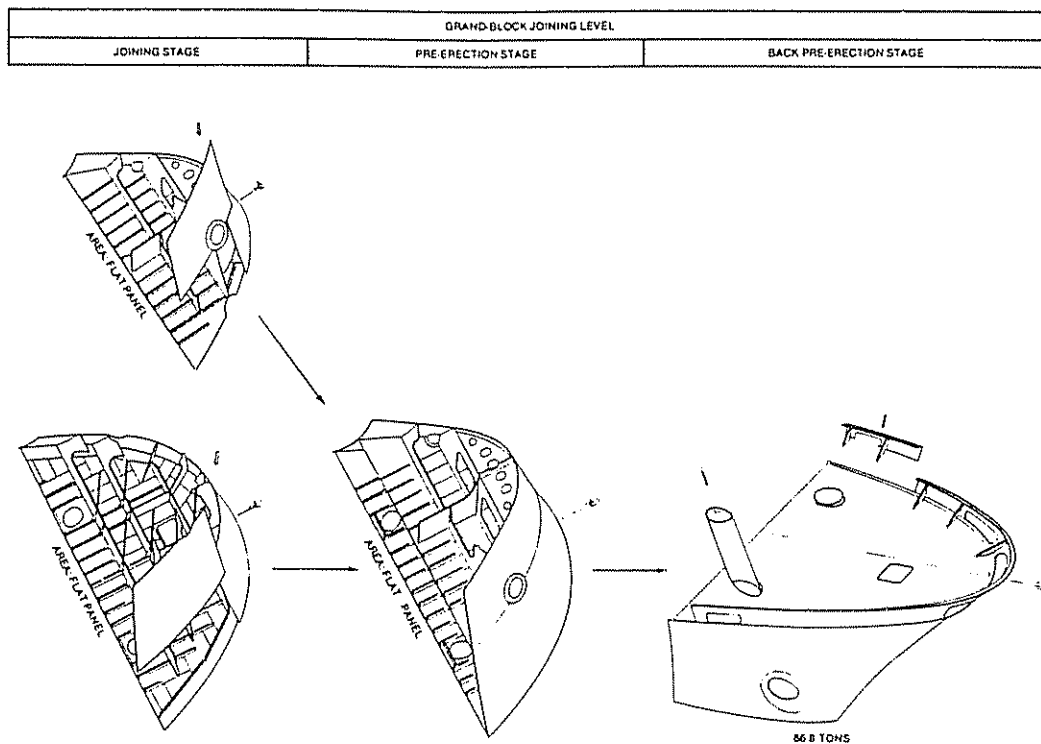


Fig. 3-21 Grand-block joining, showing a forecastle and the upper deck in a fore body

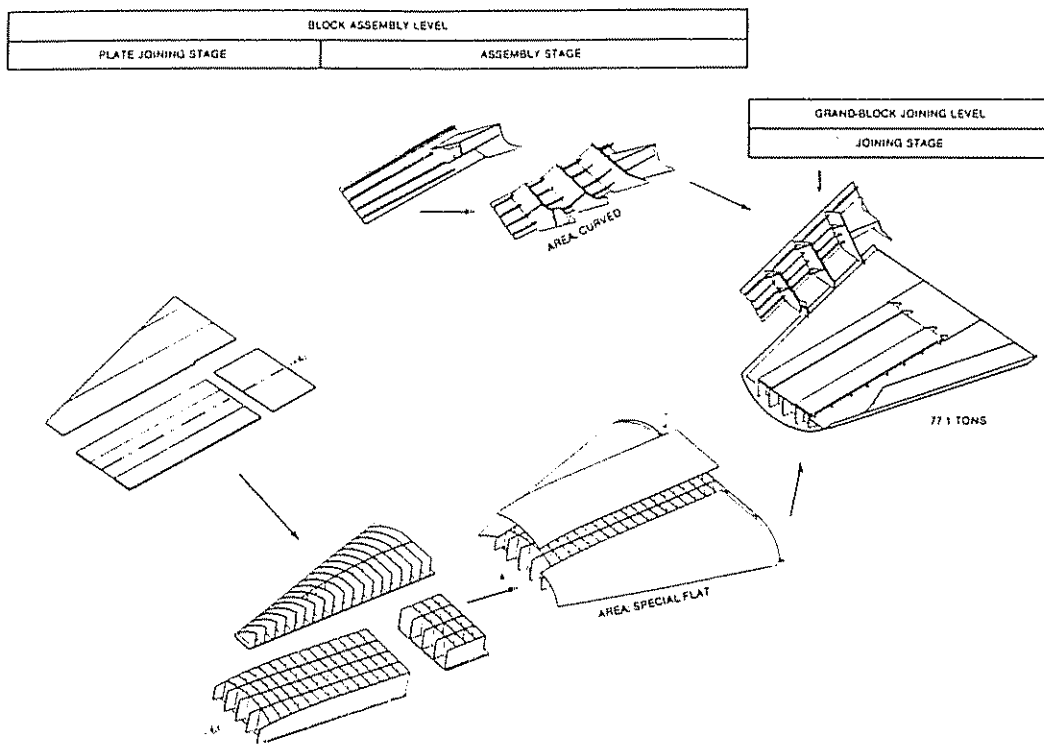


Fig 3-22 Block assembly and grand-block joining, showing the bottom of an engine room

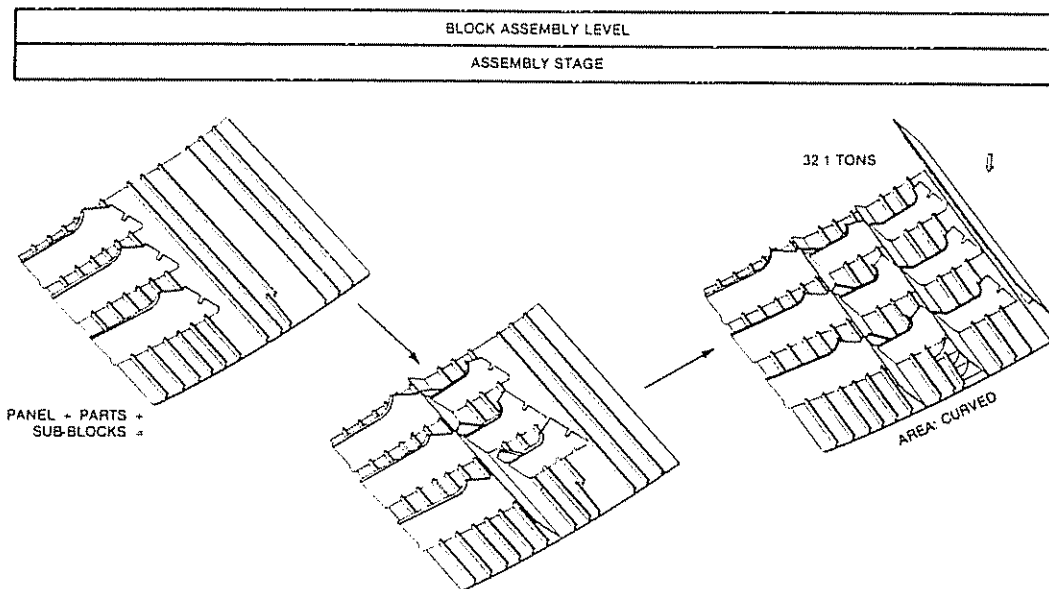


Fig 3-23 Block assembly, showing the side shell of an engine room

responding to a zone/problem area/stage are called pallets. Pallets sequenced in their order for execution compose the outfitting plan. Adapting a pallet list from a previously constructed ship avoids much duplication of effort. It is a singular means for managers to control the application of experience, as opposed to depending on experience vested in individuals.

3.2.2. *On-unit, On-block, and On-board Outfitting.*

On-unit refers to a zone which defines an arrangement of fittings to be assembled in-house, independent of hull structure. Assembly of such fittings is called outfitting on-unit. It enhances safety and reduces both required man-hours and durations which would otherwise be allocated to outfitting on-block and on-board.

On-block for outfitting purposes refers to a rather flexible relationship between block and zone. The assembly of fittings on any structural subassembly (e.g., semi-blocks, blocks, and grand blocks), is referred to as outfitting on-block. The zone applies to that region being outfitted. The fitting arrangement on the ceiling of a block set upside down is a zone. Following block turnover, the fitting arrangement on deck is another zone.

On-board is a division or zone for packaging work for the assembly of fittings during hull erection and after launching. An ideal zone for outfitting on-board avoids the need to disperse and/or continuously relocate resources, particularly workers. In general, compartments defined by shell, bulkhead, deck, or other partitions are suitable. Even entire cargo holds, tanks, engine rooms, superstructure decks, or weather decks can be useful zones for final outfitting on-board stages.

ZOFM planners, addressing the need to break down outfit work into packages, consider outfit components for all systems in an on-board zone and try to maximize the amount fitted into on-block zones. Similarly, they con-

sider outfit components for all systems in an on-block zone and try to maximize the amount fitted into on-unit zones. Their objective is to minimize outfit work during and after hull erection.

As in HBCM, maximum productivity is achieved when:

- work is equally apportioned to work packages grouped by product aspects at the most efficient manufacturing levels
- uniform and coordinated work flows are maintained by shifting workers, overtime, and/or short-term schedule adjustments

Work packages are optimally sized when their work contents are nearly uniform. The balancing of work among packages requires consideration of groups of components by the product aspects zone, problem area, and stage. This balancing of work strongly affects other factors, such as the allocation of manpower and scheduling. Other important objectives of ZOFM planners include:

- shifting fitting work, especially welding, from difficult positions to easier down-hand positions, thus reducing both the man-hours needed and the durations required
- selecting and designing components so as to organize groups of fittings that can be assembled on-unit, thus simplifying planning and scheduling by keeping the different types of work separate at the earliest manufacturing levels
- transferring work from enclosed, narrow, high, or otherwise unsafe locations to open, spacious, and low places, thus maximizing safety and access for material handling
- planning simultaneous execution of many work packages, thus decreasing the overall fitting duration

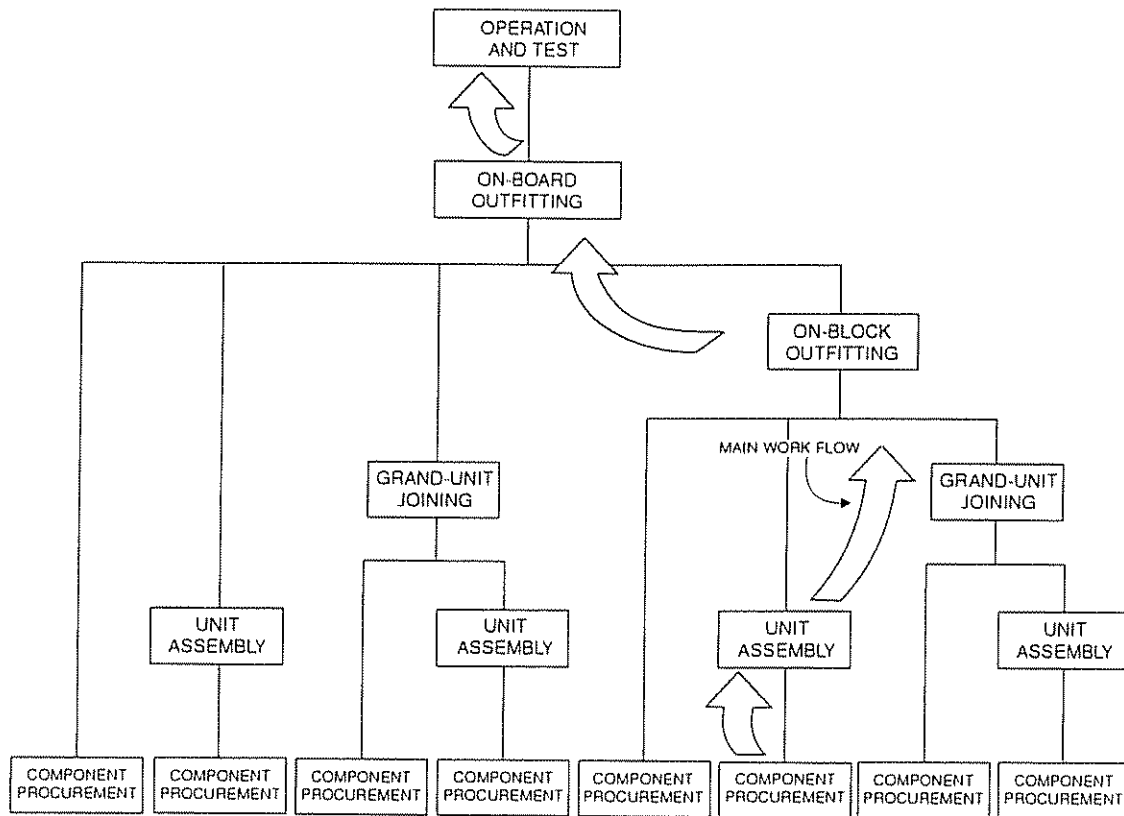


Fig 3-24. Zone outfitting method (ZOFM) manufacturing levels

Considering these requirements, it is practical to plan outfitting in six manufacturing levels as shown in Figure 3-24. The component, unit, and grand-unit levels are executed independent of the hull structural zones in which they will eventually be fitted. The on-block and on-board levels are, of course, entirely dependent on structural entities.

In order to minimize the impact of these dependencies, fitting components should be assembled into units and grand units as much as possible, provided that they are truly independent (i.e., rigid and stable without extraordinary temporary reinforcements or supports). This approach is the primary means for shortening the durations required for on-block and on-board outfitting.

Within each level, other than that for grand units, the resulting proposed interim products are examined for similarities in their product aspects. Then, as in the HBCM, they are grouped by similarities to further modularize the production process, justify expensive but highly efficient facilities, and achieve manpower savings.

Typical groupings by product aspects are shown in Figure 3-25. Horizontal combinations characterize the various types of work packages that are requisite and sufficient for the work to be performed for each manufacturing level. Vertical combinations of the various work package types denote the process lanes for outfitting work flow which correspond to those simply illustrated in Figure 3-5.

As the implementation of ZOFM progresses, the need becomes greater for balanced planning and scheduling, and cooperation between hull construction, outfitting, and painting planners.

3.2.3. Component Procurement. As shown in Figures 3-24 and 3-25, component procurement is the initial manufacturing level. It produces interim products or zones for outfitting for which no further subdivision is needed by the shipyard. Typical work packages and material requisitions are grouped by zone and by problem area to address the separate procurement problems:

- in-house manufacturing
- outside manufacturing
- purchasing

These problem areas are further classified by requirements for manufacturing drawings, purchase order specifications, and raw materials, as shown in Figure 3-26. When preparations for outside manufacturing are the same as for in-house, a shipyard retains better control, avoids vendor drawing approvals, and makes eligible many small firms that do not have design or purchasing departments.

After having performed groupings by zone, problem area, and similarities in component types and sizes, further grouping is made by stage as follows:

- design and material preparation or nil
- manufacturing or nil
- palletizing

The palletized components are assigned to their respective work packages at subsequent manufacturing levels.

3.2.4. Unit Assembly and Grand-unit Joining. Just as a block is a key zone for hull construction, a unit is a key zone for outfitting which, as illustrated in Figures 3-24 and 3-25, may require only a single manufacturing level.

Productivity is enhanced when units are similar in required man-hours for assembly, numbers of components, volume, weight, design standards, etc. Grouping by such similarities facilitates organizing and uniformly loading process flow lanes.

As indicated in Figure 3-27 (Plate I), unit sizes vary significantly. Therefore, two problem areas are designated at the unit assembly level:

- large size
- small size

The distinction is by required lift capacity. Large units weigh more and small units weigh less than one ton. If many small units are planned for assembly of larger units, another manufacturing level may be included for sub-unit assembly. Problem areas at the unit level could be further subdivided into:

- machinery unit (machinery combined with all adjacent components, including foundation, pipe pieces, valves, supports, walkways, ladders, etc.)
- pipe unit (no machinery, just pipe pieces combined with valves, supports, walkways, etc.)
- other (hatch covers with coaming, masts, etc.)

Stage for unit assembly is divided as:

- assembly
- welding or nil

The welding stage applies for extensive or special welding requirements, as welding incident to routine unit assembly is performed by fitters during the preceding assembly stage.

Some shipyards have developed machinery units into standard arrangements which can be adapted for various types and sizes of ships. As required design and material definition is already available, much planning for a standard machinery unit can progress just



Fig. 3-27(a)



Fig. 3-27(b)



Fig. 3-27(c)



Fig. 3-28(a)

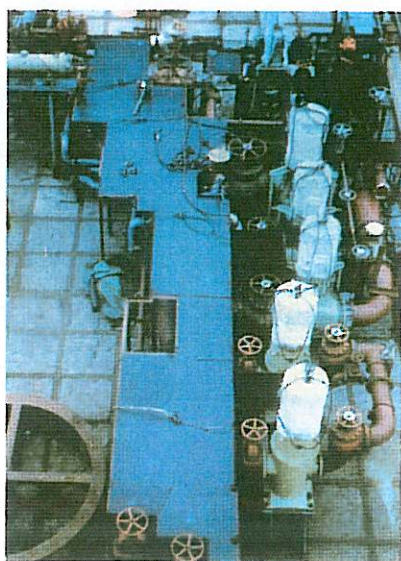


Fig. 3-28(b)



Fig. 3-29

Fig. 3-27. Outfit units. (a) An engine room tank top unit. (b) Pumps, valves, pipe pieces, and foundations incorporated as a unit. (c) Pneumatic tubing and supports form a small unit. Fig. 3-28 (a & b). Typical machinery outfit units (the same problem area). Fig. 3-29. Machinery outfit unit assembled on a common foundation (courtesy Avondale Shipyard).

PLATE II



Fig. 3-35



Fig. 3-36

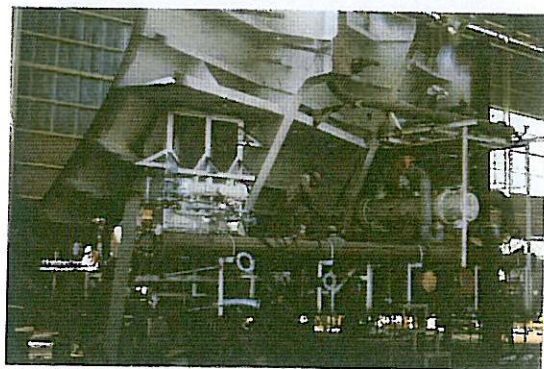


Fig. 3-37



Fig. 3-38



Fig. 3-39



Fig. 3-40

Fig. 3-35. Engine room tank top components fitted on-block. Fig. 3-36. Outfitted engine room blocks erected over previously landed outfit units (courtesy Avondale Shipyard). Fig. 3-37. Downhand outfitting on-block, in an upside-down

block. Fig. 3-38. On-block outfitting and painting, on the ceiling and on the deck. Fig. 3-39. Two complex blocks, outfitted together, upside down, to ease erection. Fig. 3-40. On-board outfitting performed prior to landing the main engine.



Fig. 3-47



Fig. 3-48

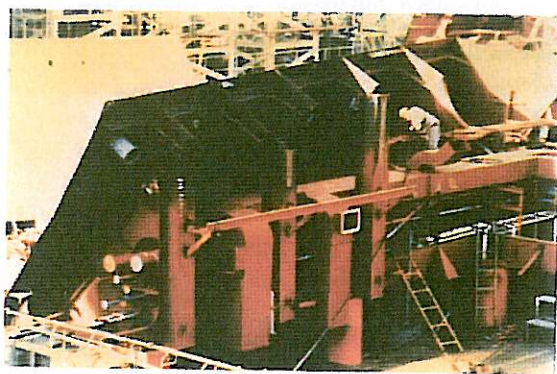


Fig. 3-49



Fig. 3-50



Fig. 3-51



Fig. 3-52

Fig. 3-47. On-block outfitting of a forecastle deck upside down. Fig. 3-48. On-block outfitting of a forecastle deck right side up. Fig. 3-49. On-block outfitting of a side shell and engine room flat upside down. Fig. 3-50. On-block outfitting of a

side shell and engine room flat right side up. Fig. 3-51. On-block outfitting of the block shown in figures 3-49 and 3-50 being completed right side up next to the building dock. Fig. 3-52. Erection of the block shown in figures 3-49 through 3-51.

PLATE IV



Fig. 3-53

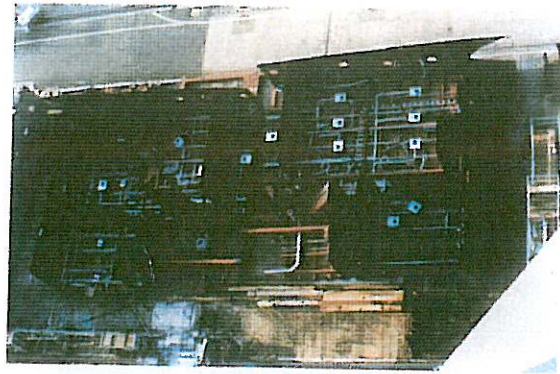


Fig. 3-54

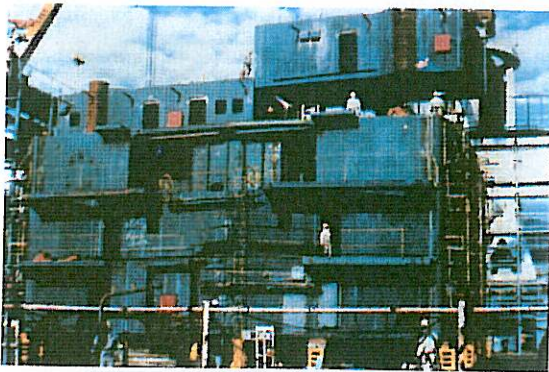


Fig. 3-55

Fig. 3-53. On-block outfitting of one-half of a superstructure deck. Fig. 3-54. On-block outfitting of another superstructure deck block. Zone, problem area, and stage are the same as in figure 3-53. Fig. 3-55. Grand-block joining of the aft half of the superstructure.



Fig. 3-56

Fig. 3-56. Erection, keel laying plus 11 workdays.



Fig. 3-57

Fig. 3-57. Erection, keel laying plus 13 workdays.



Fig. 3-58



Fig. 3-59



Fig. 3-60



Fig. 3-61



Fig. 3-62



Fig. 3-63

Fig. 3-58. Erection, keel laying plus 15 workdays.
 Fig. 3-59. Erection, keel laying plus 19 workdays.
 Fig. 3-60. Erection, keel laying plus 22 workdays.

Fig. 3-61. Erection, keel laying plus 22 workdays.
 Fig. 3-62. Erection, keel laying plus 24 workdays.
 Fig. 3-63. Erection, keel laying plus 24 workdays.



Fig. 3-64



Fig. 3-65



Fig. 3-66



Fig. 3-67



Fig. 3-68

Fig. 3-64. Erection, keel laying plus 27 workdays.
 Fig. 3-65. Erection, keel laying plus 28 workdays.
 Fig. 3-66. Erection, keel laying plus 29 workdays.
 Fig. 3-67. Erection, keel laying plus 29 workdays.
 Fig. 3-68. Operation and test (vessel launched 43 workdays after keel laying, delivered seven months after starting fabrication).

PLANG LEVEL	MFG LEVEL	PRODUCT ASPECTS										CODES										
		ZONE		AREA			STAGE					ZONE	AREA	STAGE								
1	6	SHIP		HULL	SUPERSTRUCTURE	MACHINERY	OPERATION AND TEST					SHIP NO.	SHIP NO.	OPERATION CODE								
2	5														ON-BOARD DIVISION	NIL	SPECIALTY/SIMILAR WORK IN SMALL VOLUME	SPECIALTY/SIMILAR WORK IN LARGE VOLUME	SPECIALTY/SIMILAR WORK BY HIGH SKILL	WELDING		NIL
																				ON-CLOSED-SPACE FITTING		
																				WELDING		NIL
ON-OPEN-SPACE FITTING																						
3	4	BLOCK	NIL	SPECIALTY/ COMPONENTS IN A LARGE QUANTITY	SPECIALTY/ COMPONENTS IN A SMALL QUANTITY	WELDING		NIL														
						ON-FLOOR FITTING																
						WELDING		NIL														
						ON-CEILING FITTING																
4	3	UNIT	NIL	LARGE-SIZE UNIT	NIL	WELDING		NIL														
5	2					JOINING																
						WELDING		NIL														
						ASSEMBLY																
6	1	COMPONENT		IN-HOUSE MANUFACTURING	OUTSIDE MANUFACTURING	PURCHASING	PALLETIZING															
MANUFACTURING							NIL															
DESIGN AND MATERIAL PREPARATION							NIL															

OUTFITTING SIGN/ ON-BOARD DIVISION CODE	BLOCK CODE	HULL ERECTION STAGE CODE
OUTFITTING SIGN/ BLOCK CODE	ON-BOARD WORK TYPE CODE	BLOCK ASSEMBLY STAGE CODE
UNIT ASSEMBLY SIGN/BLOCK OR ON-BOARD DIVISION OR MACHINERY UNIT CODE	BLOCK OR ON-BOARD DIVISION OR MACHINERY UNIT CODE	GRAND-UNIT SIGN
UNIT SIGN		
COMPONENT CODE/ PALLET CODE		
COMPONENT PROCUREMENT SIGN		
NO SIGN		

Fig 3-25. ZOFM classification by product aspects

PROBLEM AREA	PROBLEM AREA SUBDIVISIONS	
	DESIGN TO FURNISH	MATERIAL TO BE FURNISHED
IN-HOUSE MANUFACTURING	MANUFACTURING DRAWING	YES
OUTSIDE MANUFACTURING	MANUFACTURING DRAWING	YES / NO
PURCHASING	PURCHASE ORDER SPECIFICATION	SELDOM / NO

Fig. 3-26 Problem area subdivisions for design and material requirements for component procurement

as if it were a single component. Two typical standard machinery units are shown in Figure 3-28 (Plate I). They represent interim products from the same problem area despite their physical differences. Figure 3-29 (Plate I) shows another typical machinery unit, utilizing a common foundation, and with machinery protected from the weather. Pipe units are generally unique because they reflect the pipe passages and details peculiar to each type and/or size ship, even among standard series ships for different owners. A variety of outfit units are shown in Figures 3-30 through 3-33.

The grand-unit joining level provides for combining two or more units in order to reduce the working times needed for fitting on-block and on-board, and to produce more stable entities for erection purposes. Classification by problem area is limited to large size unit or nil. Phasing by stage is:

- joining
- welding or nil

The welding stage applies only if there are special or extensive welding requirements

3.2.5. On-block Outfitting Outfitting components, units, and grand units are sometimes fitted in a block zone defined for hull construction. However, when they are to be fitted to ceilings, blocks should be inverted because fitting downhand enhances safety

and efficiency. Therefore, the outfit zone for a block set upside down encompasses everything fitted to the ceiling. Following block turnover, the outfit zone encompasses the components, units, and/or grand units fitted to the floor. Turnover represents a change in stage. Specifying a zone by stage for each side suffices for absolute control of on-block outfitting.

Similarly, outfit items should be fitted in the zone of a double bottom block before its tank top panel is installed. Then at a later stage, a different outfit zone encompasses everything to be fitted to the tank top. The primary goals of this manufacturing level are to outfit ceilings and double bottoms when blocks can be manipulated to provide ideal access.

Typically, the divisions by problem area address problems which are inherently different, so that each work package for outfitting on-block can be assigned to the appropriate team of assembly specialists for hull, machinery, or superstructure. These classifications are further subdivided by the quantities of items to be fitted, resulting in the following six problem area divisions:

- hull: large quantity or small quantity
- machinery: large quantity or small quantity
- superstructure: large quantity or small quantity

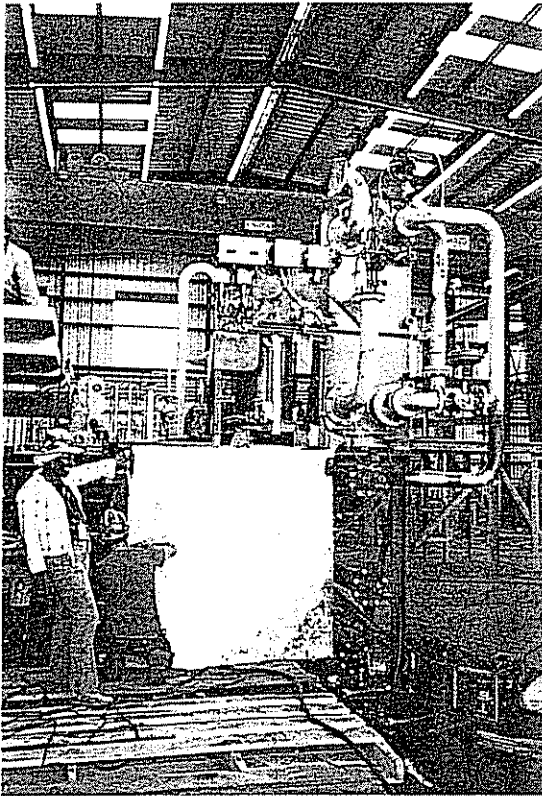


Fig 3-30

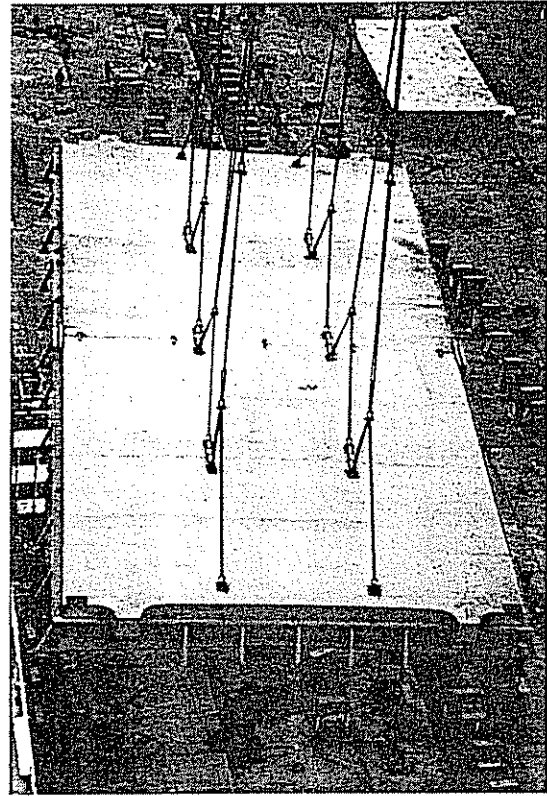


Fig 3-31

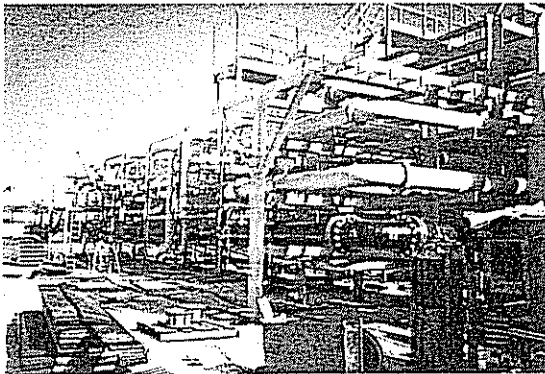


Fig 3-32

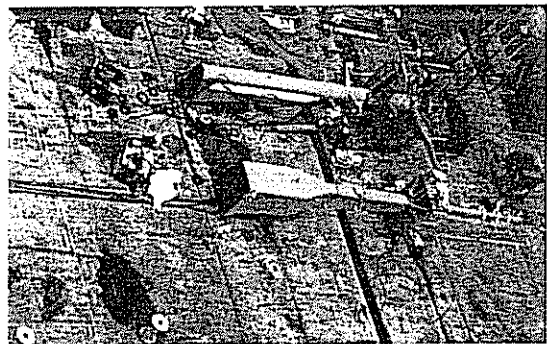


Fig 3-33

Fig 3-30 Engine room outfit unit (courtesy Avondale Shipyard). Fig 3-31. A hatch cover and coaming unit. Fig 3-32 Very complex piping units, for the deck of a product tanker (courtesy Avondale Shipyard). Fig 3-33 Mast units.

When the items to be fitted compose a small quantity per block, outfit work can be performed at the site where the block was assem-

bled. When a large quantity is planned, the completed block should be transferred to an indoor or outdoor region designated for out-

fitting in accordance with an on-flow concept. On-flow means work packages start and complete in unison.

Separation by stage is in accordance with the following sequence which reflects block turnover:

- on-ceiling fitting
- on-ceiling welding or nil
- on-floor fitting
- on-floor welding or nil

The welding stages apply only for special or extensive welding requirements. On-ceiling fitting and welding usually are optimum for blocks. However, most on-floor fitting and welding take place after on-ceiling outfitting is completed, blocks are turned over, and blocks are joined to create grand blocks. In order to simplify the erection schedule and minimize duration in the building dock, such on-floor outfitting should include all grand units, units, and components to the maximum extent possible. Figures 3-34 through 3-39 show on-block outfitting (see Plate II for figures 3-35 to 3-39). Outfitted blocks can be erected in combination with outfit units (as shown in Figure 3-36). On-block outfitting work is often greatly facilitated by block turnover for downhand on-ceiling outfitting and painting (see Figures 3-37 and 38). Complex blocks may be outfitted together to ensure accurate fits at erection.

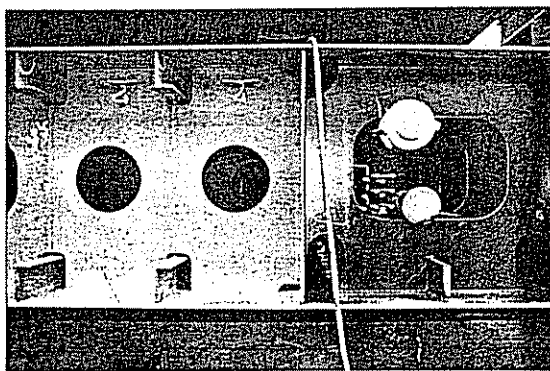


Fig 3-34. On-block outfitting in a pipe tunnel under a cargo hold

3.2.6. On-board Outfitting. Outfitting on-board may seem at first to be the same as conventional outfitting. However, the work required is susceptible to the same analyses as for on-unit and on-block outfitting. As a consequence, zone/problem area/stage control is applicable. Much on-board outfit work progresses simultaneously with hull erection, as shown schematically in Figure 3-5. Ideally, outfitting on-board should be limited to:

- fitting components, units, and/or grand units that are too large or too heavy to fit on-block (e.g., main engines, diesel generators, most units and grand units for engine room tank top, etc.)
- fitting fragile and weather-vulnerable components that could be damaged if installed before compartments are enclosed (joinery, insulation, electronic equipment, etc.)
- connecting between components, units, and grand units that are either fitted on-block or on-board

One useful method of classifying work packages by problem area simultaneously addresses the teams of specialists needed, work volume sizes, and skill requirements. This classification is:

- similar work in small volume
- similar work in high volume
- high-skill requirements

These categories are applicable to hull, machinery, and superstructure.

Variety work in small volume should be encompassed in an on-board zone for execution by a team having the needed variety of skills. Variety work in large volume should be divided by similarities in components and units or sets of components and/or units. Zones for such problem areas should not be too long, wide, scattered, or otherwise unfavorable for execution and supervision of work. At the same time, planners must regard the

need for high-skill fitting work required in many ship compartments. In such cases, large zones grouped by specific problem areas could be most beneficial. Stage for on-board outfitting could be divided into:

- open-space (blue sky) fitting
- open-space (blue sky) welding or nil
- closed-space fitting
- closed-space welding or nil

The welding stages apply only if there is special or extensive welding to be done. Open-space fitting and welding should be completed before closures imposed by the continuing erection of blocks in order to take full advantage of easy access. Therefore, such work should be incorporated in the erection schedule. Closed-space fitting and welding activities should be minimized as much as practicable as they require more working hours, more transportation services, and longer durations (see Figure 3-40, Plate II).

The on-board outfitting level uses on-board divisions as zones which are subdivisions of the ship as a zone as for the erection level in hull construction work.

3.2.7. Operation and Test The operation and test level applies to work required to assess the performance of each ship's functional systems. At this level, zone is the entire ship. Problems are grouped to match teams of specialists to the hull, machinery, and superstructure areas.

Operation and test are regarded as a single stage. Thus, at this level, work is packaged by one or more systems within each of the problem areas defined for the specialist teams. It is the traditional method for planning operation and test work.

3.3. Zone Painting Method

The Zone Painting Method (ZPTM) is a natural extension of the logic employed in both HBCM and ZOFG. It transfers much paint-

ing work, traditionally performed in a building dock or at an outfit pier, to preceding manufacturing levels by integrating painting with hull construction and outfitting processes. Painting is treated as another assembly process accomplished at each manufacturing level, as shown in Figure 3-41. There are certain prerequisites for successful application of ZPTM:

- the painting interval between one coat and a next coat must be shorter than the allowable exposure period for the former
- each hull block should be virtually finished in order to minimize surface preparation and painting rework caused by further cutting, fitting, and welding
- the shop primers applied to plates and shapes should not impede efficient cutting and welding

The above requires that hull, outfitting, and painting planners work together to control the durations between the shop primer and primer levels, and between the primer and finish undercoat levels. Additionally, managers must ensure effective accuracy control to limit the need for surface preparation and painting rework resulting from inaccurately produced interim products.

The main planning objectives for shifting paint-related work to the manufacturing levels prior to on-board painting are to:

- shift positions from overhead to down-hand or at the minimum to vertical, from high to low places, and from confined to readily accessible places
- facilitate the use of temperature- and humidity-controlled buildings, especially for sophisticated coatings
- provide safer environments without extraordinary devices that would encumber workers
- prevent in-process rust and associated rework

- minimize scaffolds needed only for surface preparation and painting
- level load work throughout the entire shipbuilding process in order to avoid large work volumes in the final stages that could jeopardize scheduled delivery

Typical classification of paint-related work packages by their product aspects is shown in Figure 3-42. Horizontal combinations characterize the various types of work packages that are requisite and sufficient for the work to be performed for each level. Vertical combinations denote the process lanes for painting work flow. Obviously, there is need for balanced planning and scheduling and cooperation between hull construction, outfitting, and painting planners. Examples of paint systems applied in accordance with ZPTM are contained in Figure 3-43

3.3.1. Shop Primer Painting This manufacturing level applies to surface preparation and application of shop primer to raw materials before they are processed to create structural parts or outfit components. Items which are to be pickled after their manufacture are usually excluded. Thus, useful divisions by problem area are:

- plate
- shapes and other

The applicable stage categories are:

- shot blasting
- painting

3.3.2. Primer Painting. This level is for application of an anticorrosive, including epoxy and inorganic zinc-silicate, which is the first coat applied to a component or an on-board

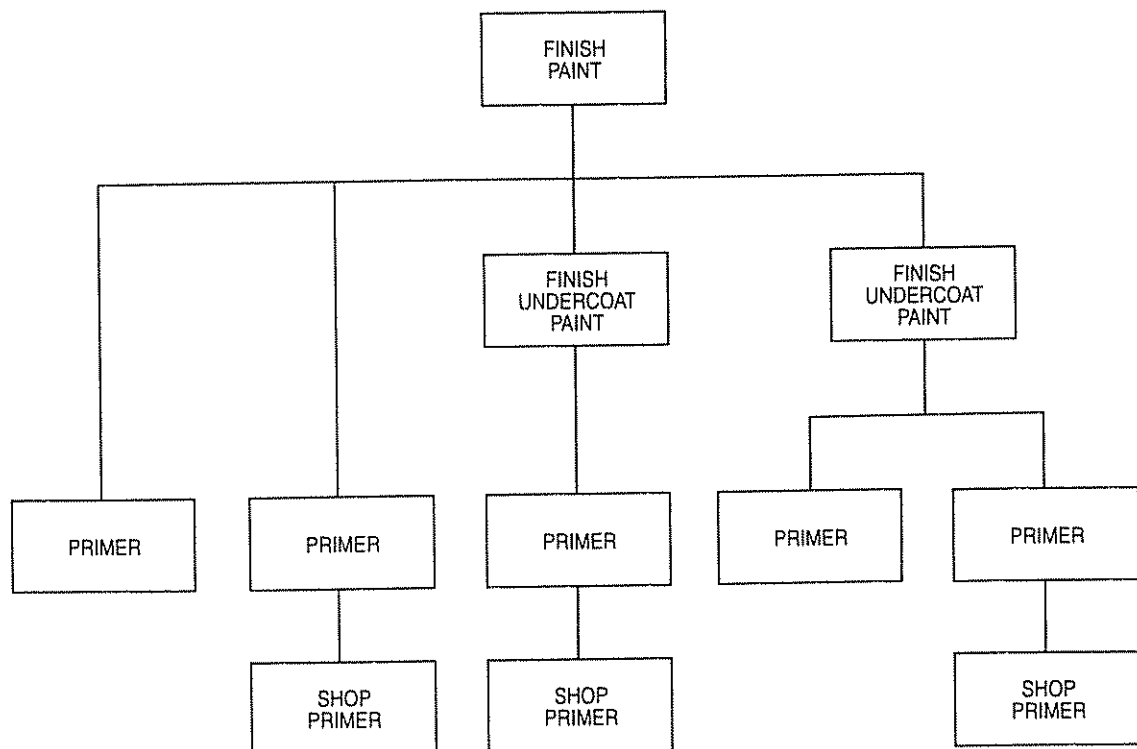


Fig. 3-41 Zone painting method (ZPTM) manufacturing levels

PLANG LEVEL	MFG LEVEL	PRODUCT ASPECTS										CODES		
		ZONE				AREA		STAGE				ZONE	AREA	STAGE
		COMPONENT	UNIT TO BE FITTED AT ON-BOARD OUTFITTING		PAINTING ON-BOARD DIVISION	PAINT MATERIAL/ NUMBER OF COATS/ TYPE OF ZONE/ PAINT SCAFFOLD REQUIRED OR NOT	PAINTING		NIL		FINISH PAINT SIGN/ ZONE CODE	PAINT CODE/ NUMBER OF COATS		
COMPONENT FITTED ON-BLOCK AT ON-BLOCK OUTFITTING			TOUCH-UP											
NIL			CLEANING											
			SURFACE PREPARATION											
BLOCK	PAINT MATERIAL/ NUMBER OF COATS/ TYPE OF ZONE/ PAINT SCAFFOLD REQUIRED OR NOT		PAINTING AFTER OVERTURNING			NIL		FINISH UNDERCOAT PAINT SIGN/ ZONE CODE	PAINT CODE/ NUMBER OF COATS					
			TOUCH-UP AFTER OVERTURNING			NIL								
			CLEANING AFTER OVERTURNING			NIL								
			SURFACE PREPARATION AFTER OVERTURNING			NIL								
	PAINTING						PAINTING							
							TOUCH-UP							
						CLEANING								
						SURFACE PREPARATION								
		PAINT MATERIAL/ NUMBER OF COATS/ TYPE OF ZONE	PAINTING AFTER OVERTURNING		NIL		PRIMER SIGN/ ZONE CODE	PAINT CODE/ NUMBER OF COATS						
			CLEANING AFTER OVERTURNING		NIL									
SURFACE PREPARATION AFTER OVERTURNING			NIL											
PAINTING														
CLEANING					CLEANING									
					SURFACE PREPARATION									
MATERIAL					PAINTING				SHOP PRIMER SIGN/ ZONE CODE	MATERIAL CODE				
	NIL				SHOT-BLASTING									
PLATE									STAGE CODE OF HBCM, ZOFM, OR PPFM					
SHAPES AND OTHER														

Fig 3-42. ZPTM classification by product aspects.

MANUFACTURING LEVEL	PAINT SYSTEM A	PAINT SYSTEM B
FINISH	COLOR	COLOR
FINISH UNDERCOAT	COLOR	COLORED PRIMER
PRIMER	PRIMER NUMBER OF COATS PER SPECIFICATION	PRIMER
SHOP PRIMER	SHOP PRIMER	SHOP PRIMER

Fig 3-43. Typical paint systems applied in accordance with ZPTM.

division (as defined in ZOFG), or a block (as defined in HBCM). These constitute the zone categories. Problem areas are grouped by:

- paint type (i.e., conventional, epoxy, inorganic zinc-silicate, etc.)
- number of coats
- type of zone

The latter further classifies each component, block, or on-board division by problem area, to anticipate:

- burn or wear damage of painted surfaces during HBCM and ZOFG succeeding manufacturing levels
- difficulty if there is a change in painting conditions (e.g., downhand to overhead, low to high, spacious to confined, etc.)
- need to maintain appearance

These considerations again demonstrate that ZPTM, ZOFG, and HBCM planning must be coordinated. Paint planners have to consider the foregoing for each zone at all ZOFG and HBCM manufacturing levels. Stage at this level is separated into the following phases:

- surface preparation
- cleaning
- touch-up
- painting

- surface preparation after block turnover or nil
- cleaning after block turnover or nil
- touch-up after block turnover or nil
- painting after block turnover or nil

The work at this manufacturing level is coordinated with ZOFG so that primer is applied just before the on-ceiling fitting stage and, following block turnover, just before the on-floor fitting stage. Nil applies to blocks that are not turned over.

3.3.3 Finish Undercoat Painting. This is the semifinal manufacturing level for paint application. Useful zone classifications are:

- components (big in size or which become relatively inaccessible after fitting on-board, such as masts, cargo booms, undersides of hatch covers, etc.)
- units which are to be fitted on-board
- outfitted blocks
- on-board divisions
- nil (applicable if epoxy is specified)

Problem area divisions are:

- paint type
- number of coats
- type of zone (as described in Part 3.3.2 for the primer painting level)
- scaffolding required only for paint

The classification of work packages by stage is the same as for the primer level.

3.3.4. *Finish Painting* Finish painting is the final manufacturing level in ZPTM. Zone, problem area, and stage classifications are the same as in the final undercoat level except that stages associated with block turnover are not applicable, and "nil" in the final stage means a finish coat will not be applied, as in the case of epoxy.

3.4. Integrated Hull Construction, Outfitting, and Painting

Integrated HBCM, ZOFG, and ZPTM for a 22,000 dwt, multipurpose cargo carrier, which is not one of a standard series, is illustrated in Figures 3-44 through 3-68 (Figures 3-47 to 3-68, see Plates III-VI). Typically, all work shown was performed during a single eight-hour shift per workday. Some nominal overtime was applied, usually for painting.

4. Pipe Piece Family Manufacture

The integration of the HBCM, ZOFG, and ZPTM represents the application of the principles of group technology to shipbuilding. Together they form a total shipbuilding system. Group technology (GT) may also be used to organize work within individual shops, such as the pipe shop or machine shop. In fact, these applications are closer to the traditional beginnings of GT. Pipe shop organization will be considered as an example of the application of GT to one particular shop in a shipyard [2].

The engine room of a 22,000 dwt diesel-propelled ship contains about 3,600 pipe pieces. The many differences among them hide commonalities that are useful for planning their manufacture. GT is used to systematically classify pipe pieces into groups or families having design and manufacturing attributes which are sufficiently similar to make batch manufacturing practical. The process is called Pipe Piece Family Manufacturing (PPFM).

The collection of seemingly different pipe pieces into such families avoids laborious job-shop type planning, scheduling, and manufacturing. Instead, different pieces within a family are designated for the same machines and tooling setups, which are arranged in a rationalized process lane. The manifestly clear

stage-by-stage progression of developing pipe pieces within such work flow lanes greatly enhances production control. Further, the separation by stages permits the switching of work flow from one process lane to another without diminishing control.

In PPFM the key zone is that which defines a planned pipe piece. It is an optimum division of a pipe line, usually consisting of:

- cut pipe (including branch when applicable)
- flanges
- elbows, sleeves, tees, etc.

A finished pipe piece appears in Figures 3-25 and 3-26 as a component from the "in-house manufacturing" problem area within the lowest ZOFG manufacturing level needed for outfitting on-unit, on-block, or on-board. Thus, zone for PPFM is different from that for HBCM, ZOFG, and ZPTM, in that it is not derived from a hull block. Because of this difference, PPFM is developed independently and is only problem area oriented, as distinguished from the zone orientations of HBCM, ZOFG, and ZPTM.

A further distinction is that PPFM is a fabrication process, as compared to the assembly processes which characterize HBCM, ZOFG, and ZPTM. Typically, PPFM is ap-

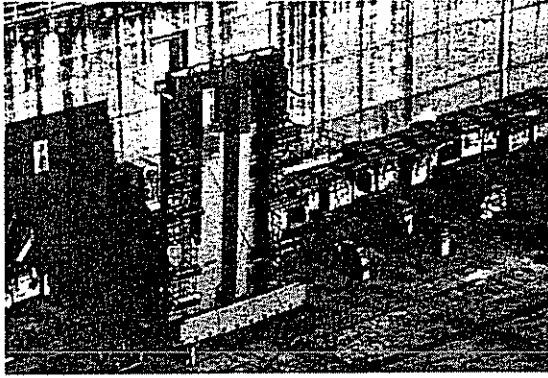


Fig 3-44

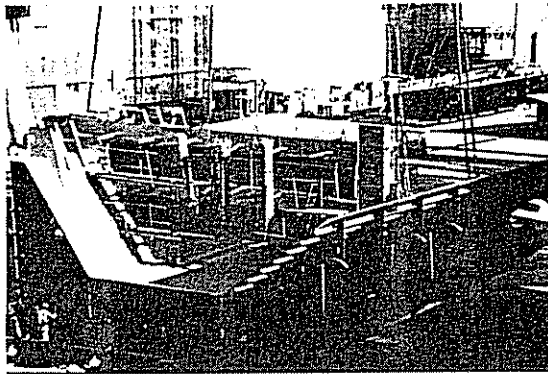


Fig. 3-45

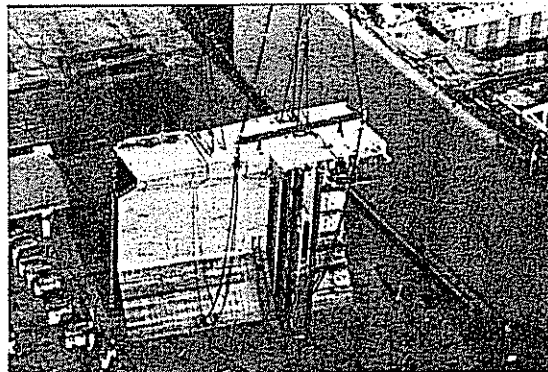


Fig 3-46

Fig 3-44 A center deck and center transverse bulkhead grand block, upside down. Fig. 3-45. A grand block, including the side shell, top side tank, transverse hopper, and side transverse bulkhead of a cargo hold. Fig. 3-46. The same grand block as in figure 3-45.

plied in the seven manufacturing levels presented in Figure 3-69. The accompanying product aspects in Figure 3-70 show that the most important considerations for classifying proposed pipe pieces by problem area must take account of similarities in:

- material specified (steel, copper, polyvinylchloride, etc.)
- bore size
- shape (straight or bent)
- length
- other factors

Horizontal combinations of the product aspects characterize the various types of work that are requisite and sufficient for the work to be performed at each manufacturing level. Vertical combinations of the various work package types denote the process lanes for pipe piece manufacturing. Typical problem area subdivisions for only the pipe fabrication, pipe piece assembly, and pipe piece joining levels are presented in Figure 3-71

The work packages, grouped by unique similarities at all levels, facilitate modularization of the fabrication processes and justification for expensive but highly efficient facilities. Whether manual or automatic fabrication methods are used, the number and variety of pipe pieces needed for ships justifies PPFM. Advantages are:

- less rearrangement of jigs and tools
- less variation in the work durations and man-hours required among the same type work packages
- better accuracy
- significant manpower savings

4.1. Work Lots

It is impractical to control PPFM with one work package per pipe piece, because each is a relatively small job and a wide variety and large number of pipe pieces are needed per ship. Control by lot (i.e., a group of work pack-

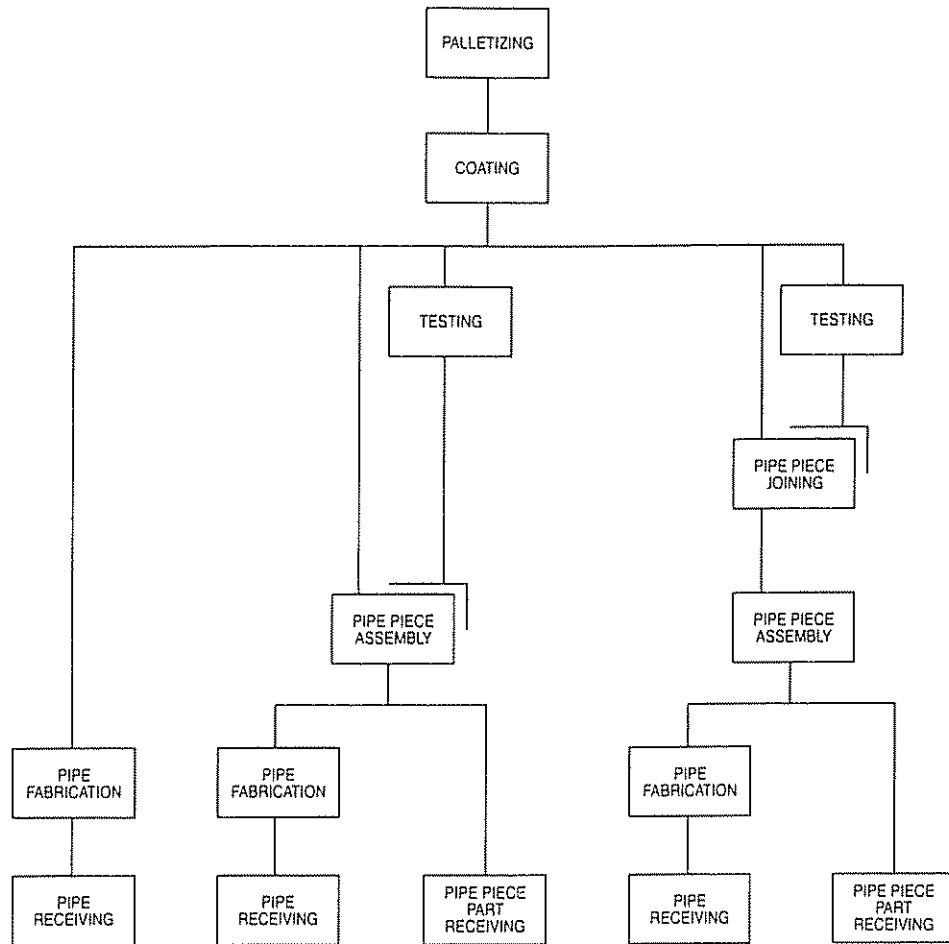


Fig 3-69 Pipe piece family manufacturing method (PPFM) manufacturing levels

ages) is far more effective, provided certain principles are applied.

Within a processing lane the optimum durations required for each work stage and the times required for material handling between stages, when summed, yield the overall duration (lead time) required for a processing lane. Thus, minimizing the time required for material handling between stages also requires careful attention. Further, the durations required to manufacture all pipe pieces of a particular family should be equal to each other. A lot should consist of a mix from different families that will fully load a facility during a designated period, such as a workday or a workweek. Thus, pipe pieces

which compose a lot could be manufactured in any random sequence without diminishing control. One very effective manually operated pipe shop posts a large calendar marked to show a color code assigned to each work week. A dab of paint marks each pipe piece in process with a color assigned per work lot. Thus, anyone can readily determine if the lot in process is on schedule. A lot should be sized by evaluating its productivity value (PV), particularly in consideration of its product resources.

4.2. Material Receiving

Material receiving is the preparation or first manufacturing level, as shown in Figures 3-69 and 3-70. Problem area is determined by

PLAN'G LEVEL	M'FG LEVEL	PRODUCT ASPECTS							
		ZONE		AREA			STAGE		
1	7	PALLET		DECK INCLUDING ELECTRICAL	ACCOMMODATION INCLUDING ELECTRICAL	MACHINERY INCLUDING ELECTRICAL	PALLETIZING		
2	6	PIPE PIECE	NIL	COATING PROCESS		COATING		NIL	
3	5					PICKLING		NIL	
4	4			TEST PROCESS		TESTING		NIL	
5	3								
6	2								
7	1			PIPE MATERIAL/ X-RAY OR NIL/ BORE/STRAIGHT OR BENT/LENGTH		FINISHING			
						WELDING			
						JOINING			
						MARKING & CUTTING		NIL	
				PIPE MATERIAL/ X-RAY OR NIL/ MAIN OR BRANCH/ BORE/STRAIGHT OR BENT/LENGTH		BENDING ON PIPE PIECE		NIL	
						FINISHING		NIL	
						WELDING		NIL	
						ASSEMBLY			
						CUT PIPE JOINING		NIL	
		CUT PIPE	NIL	PIPE MATERIAL/PIPE MAIN OR BRANCH BORE		MACHINING		NIL	
						BENDING ON CUT PIPE		NIL	
						MARKING & CUTTING			
		MATERIAL	PIPE	PIPE PIECE PART	RECEIVING				

CODES		
ZONE	AREA	STAGE
PALLET CODE	SHOP NO.	SHOP NO.
PIPE PIECE NO.	COATING CODE	COATING CODE
	PIPE PIECE MANUFACTURING LANE CODE	PIPE PIECE MANUFACTURING LANE CODE
PIPE PIECE NO/ MAIN OR BRANCH SIGN		
MATERIAL CODE	MATERIAL CODE	NIL

Fig 3-70 PPFM classification by product aspects

LEVEL	PIPE PIECE JOINING					
	PIPE PIECE ASSEMBLY					
AREA	PIPE FABRICATION					
	MATERIAL	X-RAY OR NIL	MAIN OR BRANCH	BORE	STRAIGHT OR BENT	LENGTH
SUB-AREA	STEEL	NIL	MAIN	SMALL	STRAIGHT	
					BENT	
				MEDIUM	STRAIGHT	SHORT
						LONG
				LARGE	BENT	
			BRANCH			
		X RAY				
	NONFERROUS					
	PVC					
	OTHER					

Fig. 3-71. Problem area subdivisions for pipe piece fabrication, assembly, and joining levels.

type of material and shape in accordance with the following:

- pipe
- flanges, elbows, tees, sleeves, etc.

Stage is simply:

- material receiving

4.3. Pipe Piece Fabrication

Pipe piece fabrication, the second manufacturing level, applies to processing of the pipe only. Problem area is grouped by:

- pipe material (steel, nonferrous, polyvinylchloride, etc.)
- main pipe or branch
- bore (small, medium, or large)

These problem area divisions and further subdivisions are incorporated in Figure 3-72. Stages for this level are:

- marking and cutting
- bending of cut pipe or nil
- machining or nil

Preferably, bending should be deferred to the next manufacturing level because it is easier to attach flanges or sleeves to straight pipe. The bending stage at the pipe fabrication level is only for those exceptional cases where flanges would lose their required orientations during bending. The machining process applies to the preparation of pipe ends for welded or threaded joints. Typical PPFM classifications and decision logic for determining pipe piece families are shown in Fig-

TYPICAL CLASSIFICATIONS FOR PIPE PIECE FAMILY MANUFACTURING (PPFM)		
PPFM NO.	PIPE PIECE CLASSIFICATIONS	SKETCH OR REMARKS
01	Straight ≤ 50 mm	
04	≤ 200 mm	
07	≥ 250 mm	
11	Bent After Fabrication ≤ 50 mm	
14	$65 \sim 200$ mm	
21	Radiographic Tested (Total Insp.)	
24	(Sampling Insp.)	
25	Hydrostatic Tested ≥ 40 kg/cm ²	
27	< 40 kg/cm ²	
31	Plastic	
34	Bent By Heating	
41	Bent Before Fabrication ≤ 50 mm	
44	$65 \sim 200$ mm	
51	Assembled ≤ 50 mm	
54	≤ 200 mm	
57	≥ 250 mm	
61	Special Coating - Lining	
69	- Galvanizing	
71	Threaded	
77	Penetrations	
81	Heating Coils	
84	Stainless Steel	
87	Non-ferrous	
90	Urgent (M)*	
91	Molded and adjusted	
92		
93	Aluminum brass pipes (M)	
95	Unit Assembled	
96	Long term** (M) Equivalent to PPFM No. 21, 24, 27 & 61	
97	Cast Steel	
99	General (M) Except for PPFM No. 96	
00	Molded and adjusted (M)	

* (M) designates manually prepared pipe-piece drawings
 ** Requires longer than average time.

Fig 3-72. Typical classifications for PPFM

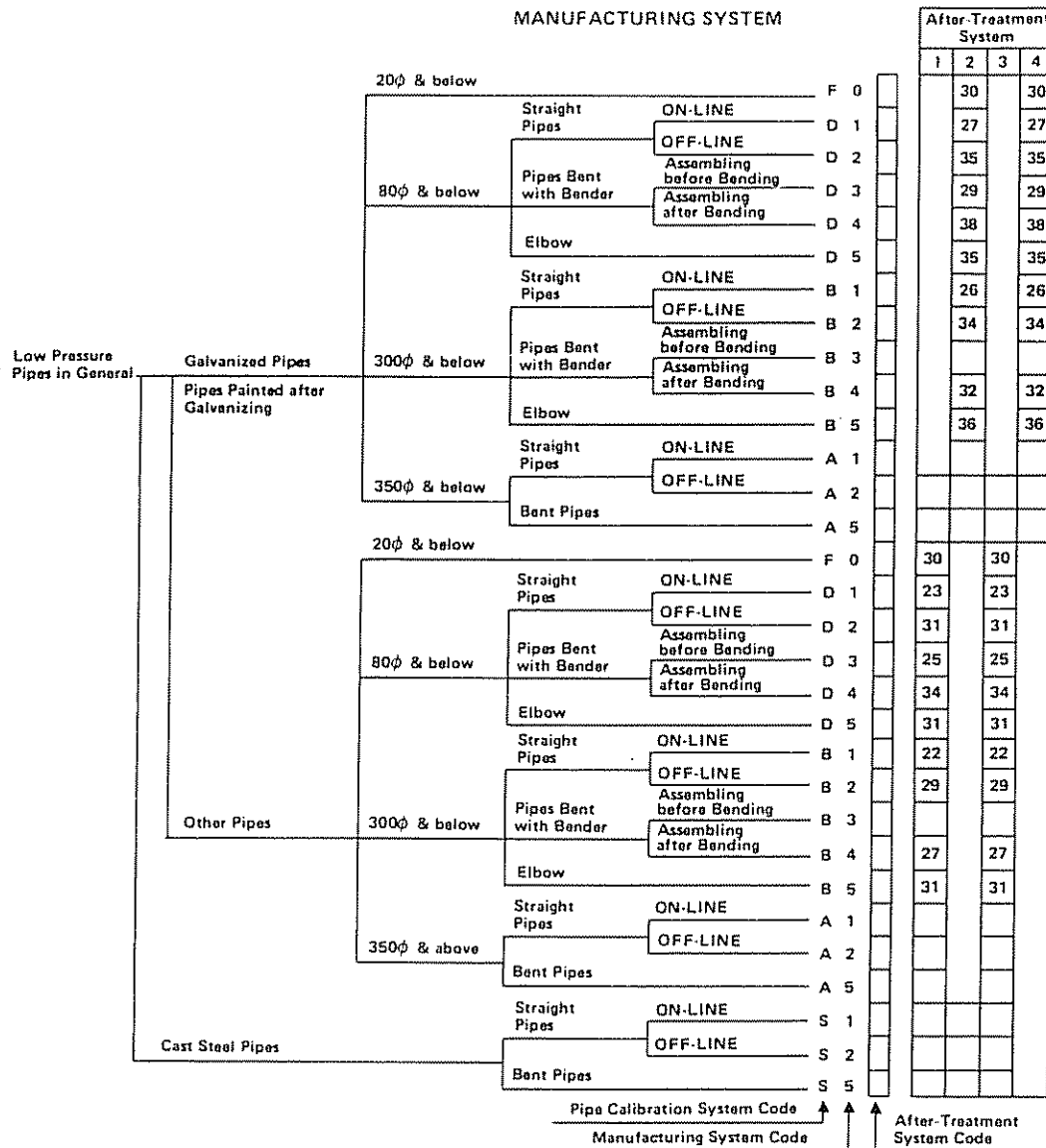


Fig. 3-73. Typical decision logic for determining pipe piece families

ures 3-72 and 3-73, respectively. Figures 3-74 through 3-76 show pictures of typical PPFM classifications.

4.4 Pipe Piece Assembly

At this manufacturing level, flanges, sleeves, etc., are attached to cut pipe. The finished assembly is the zone for a pipe piece except for main and branch subassemblies which

are to be joined to create a branch pipe piece during the next manufacturing level. Problem area is subdivided as follows:

- X-ray test or nil
- short, straight or bent
- long straight

Stage is phased in accordance with the following sequence:

- cut pipe joining or nil
- assembling
- welding or nil
- finishing (grinding or machining) or nil
- bending or nil

Cut pipe joining is for producing a cut pipe longer than a standard length (the break between short and long straight in the problem area subdivision). The welding and finishing stages for main and branch subassemblies

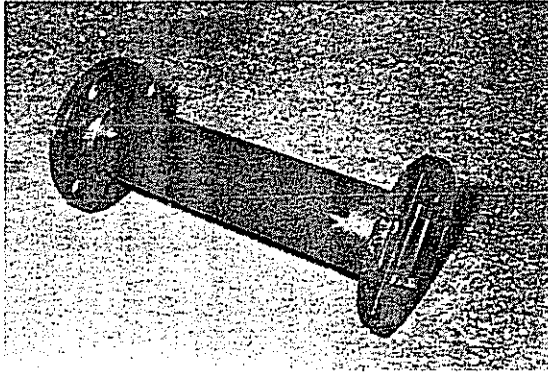


Fig 3-74(a)

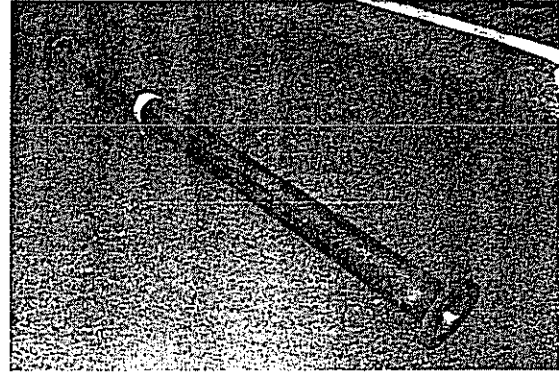


Fig 3-74(b)

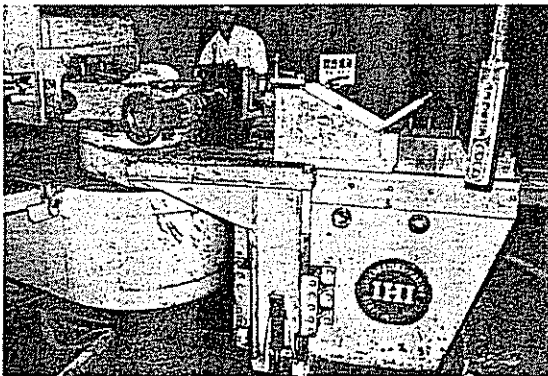


Fig 3-74(c)

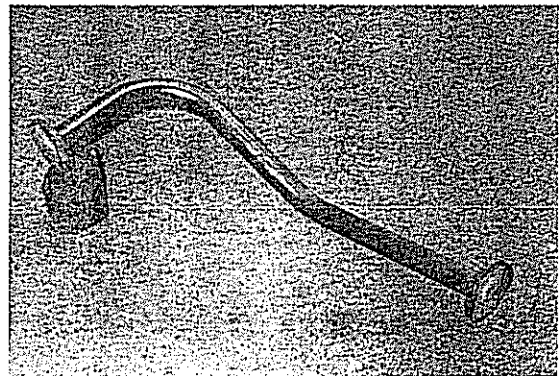


Fig 3-74(d)

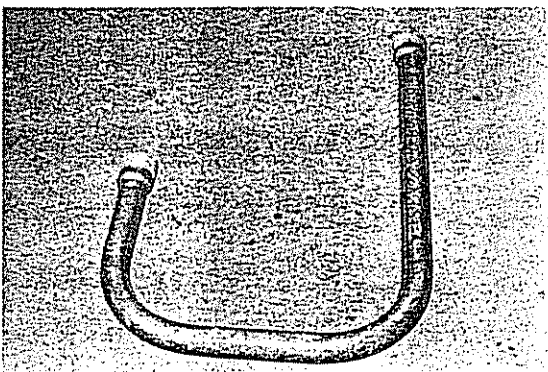


Fig 3-74(e)

Fig. 3-74. Typical PPFM classifications. (a) Straight. (b) Straight. (c) Bent after fabrication. (d) Bent after fabrication. (e) Bent after fabrication.

are deferred until after they are joined to create a branch pipe piece during the next manufacturing level. Grinding on non-tested pipe

pieces and machining on pipe pieces to be X-ray tested, or on pipe for hydraulic systems, are deferred to the next manufacturing level.

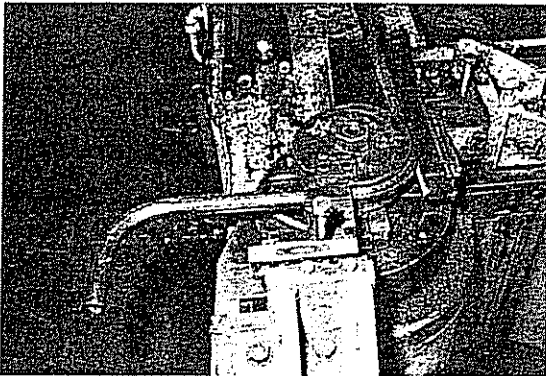


Fig. 3-75(a)

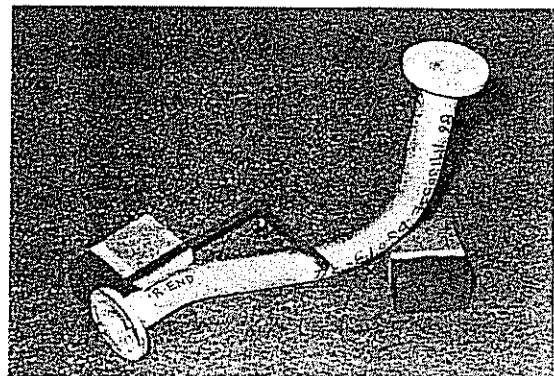


Fig. 3-75(b)

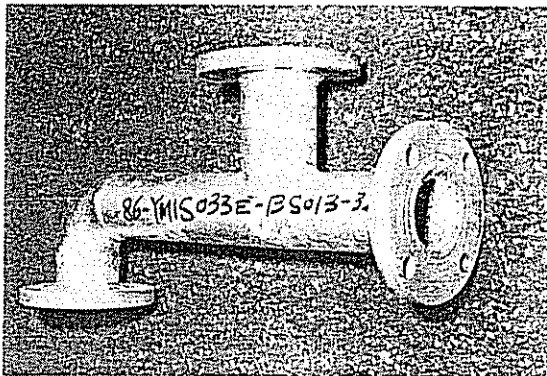


Fig. 3-75(c)

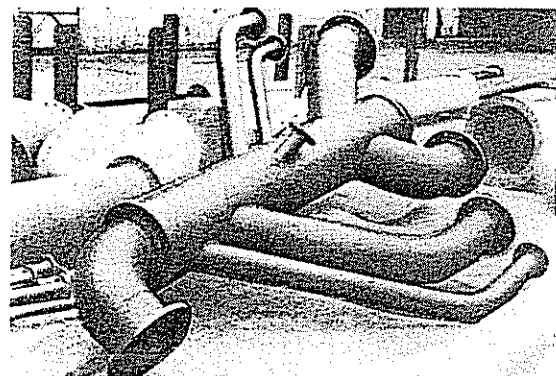


Fig. 3-75(d)

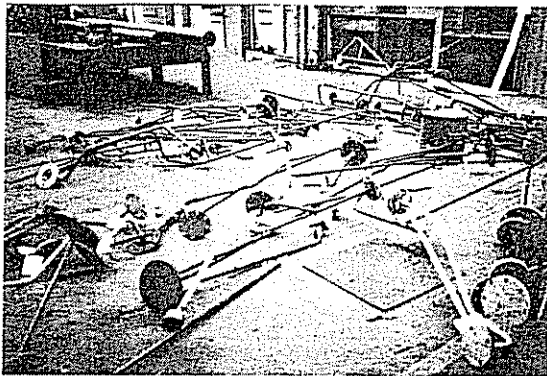


Fig. 3-75(e)



Fig. 3-75(f)

Fig. 3-75. Typical PPFM classifications (a) Bent before fabrication. (b) Bent before fabrication. (c) Assembled (d) Unit assembled. (e) Mocks for molding. (f) Adjustable (loose flange).

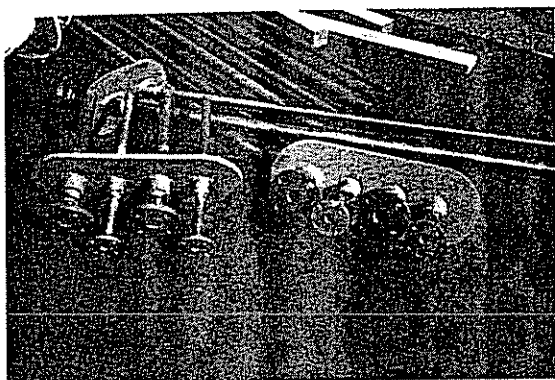


Fig. 3-76(a)

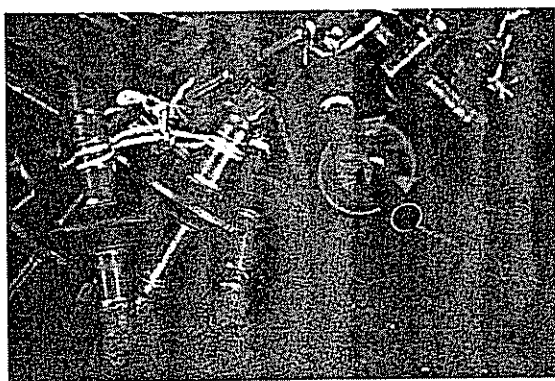


Fig 3-76(b)

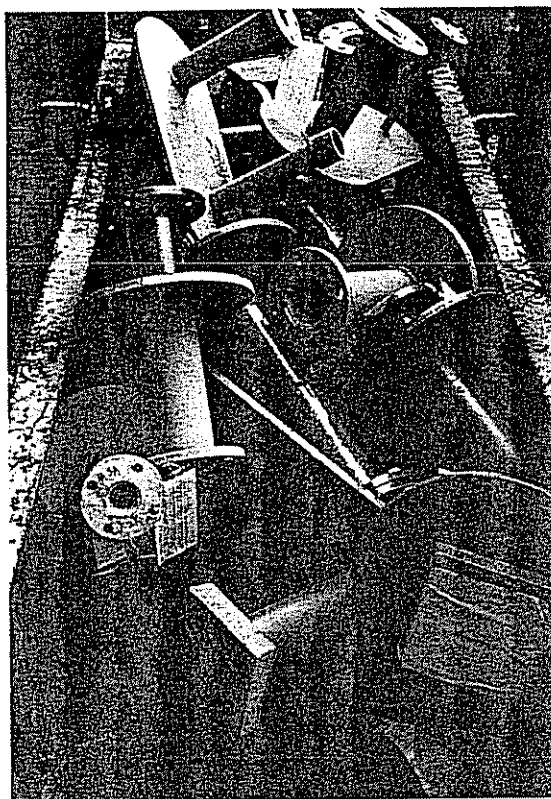


Fig 3-76(c)

Fig. 3-76 Typical PPFM classifications of penetrations (a) Parallel runs (b) Copper tubing brazed to steel (c) Completed penetrations

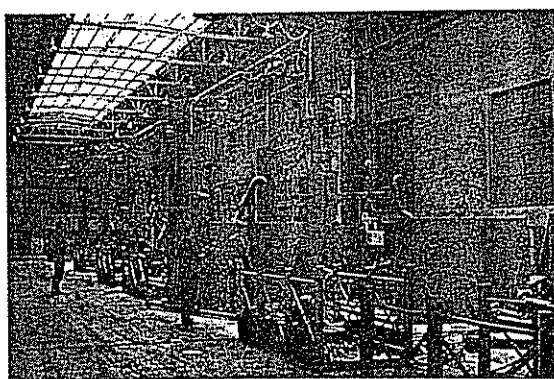


Fig. 3-77. Pipe piece assembly work stations



Fig. 3-78 Pipe piece coating

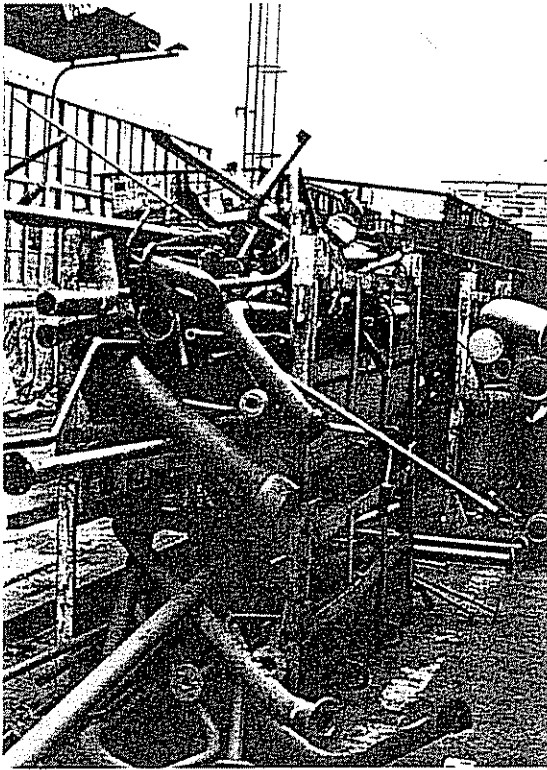


Fig 3-79 Pipe piece pallets and pallet storage areas

Figure 3-77 shows pipe piece assembly workstations, with containers for completed assemblies and lanes wide enough for forklift trucks.

4.5. Pipe Piece Joining

The pipe piece joining level is for performing all joining not previously accomplished. Typically, it would apply to joining a main pipe subassembly to a branch pipe subassembly or to other parts such as elbows, tees, sleeves, etc. Thus, the pipe pieces finished at this level are neither simple nor straight.

Problem area is grouped identically to that for the previous manufacturing level, except that the "main or branch" subdivision shown in Figure 3-71 is not required. Stage is phased as:

- marking and cutting or nil
- joining
- welding
- finishing (grinding or machining)

The marking and cutting stage at this level pertains to boring a hole in a main pipe subassembly as preparation for joining a branch.

4.6 Testing and Coating

Testing and coating are performed at the places where each pipe piece first constitutes a zone. This means places where final work for pipe piece assembly (straight or simple) and pipe piece joining (branches, etc.) is performed. Problem area for testing is grouped by the different test processes required. Stage is simply:

- testing or nil

Problem area for coating is grouped by the different coating processes required. Stage is phased as:

- pickling or nil
- coating or nil

Pipe piece coating often does not require special facilities (see Figure 3-78).

4.7. Palletizing

Palletizing is the final manufacturing level and provides for the sorting of all pipe pieces (including electrical conduit) in accordance with structured material lists. Each list establishes the pipe piece requirements for a specific pallet. Problem areas for palletizing are:

- hull
- machinery
- superstructure

Stage is simply:

- palletizing

Figure 3-79 shows typical pallets and palletizing areas.

References

1. Okayama, Y., and L.D. Chirillo, *Product Work Breakdown Structure*, National Shipbuilding Research Program, Maritime Administration, in cooperation with Todd Pacific Shipyards Corporation, revised December 1982.
2. Chirillo, L.D., R.D. Chirillo, C.S. Jonson, and M. Kasama, *Pipe Piece Family Manufacturing*, Maritime Administration, in cooperation with Todd Pacific Shipyards Corporation, March 1982.

METAL MANUFACTURING AND CONSTRUCTION PROCESSES

1. Hull Materials

The materials used in shipbuilding may be conveniently discussed in the categories of hull construction, outfitting, and painting. The complexity of functional requirements of a ship results in the use of a wide variety of materials. Structural materials are required to assure structural and watertight integrity, in addition to providing a platform for accomplishing the ship's mission objectives, such as carrying cargo or passengers. Additionally, structural materials are required to support machinery and equipment. Ships are made primarily of metal. Various grades of steel predominate, although aluminum is sometimes used for superstructures of ships in which weight or stability is a critical factor.

Outfit systems are required to perform a wide variety of functions, such as main ship propulsion, hotel services, and pumping. Within outfit, the major categories are machinery, piping, HVAC (heating, ventilation, and air-conditioning), electrical, accommodations, deck fittings, cargo-handling equipment, and combat systems for naval ships. Many of the components used in outfit systems are purchased from outside vendors and installed by the shipbuilder. Included in this category are main engines, generators, motors, pumps, valves, winches, chocks, cleats, and

watertight doors. A second category of outfit components are manufactured into parts within the shipyard from raw materials, such as sheet metal, or from materials purchased in bulk, such as pipe and tubing, electric cable, joinery materials, and insulation. Various types of paint and coating materials, and materials for surface preparation, are also used. These are all likely to be purchased rather than manufactured by the shipyard.

The discussion of shipbuilding materials is intended to indicate major impacts of specific materials on shipbuilding processes. The major effect is in the area of hull materials. Consequently, discussion of the impact of specific materials on outfitting and painting will be included within those subsections of this chapter dealing with the outfitting and painting processes. This section will concentrate on hull materials.

1.1. Structure of Metals

Metals exist in nature in chemical compounds. These compounds, or ores, must be refined to produce pure metals or combinations of metals and other elements which possess properties that make them usable as structural materials. The refining and use of

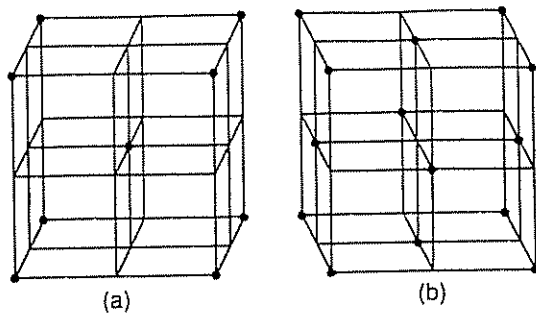


Fig. 4-1. Arrangement of atoms in cubic lattices
(a) Body centered. (b) Face centered.

metals alters their properties, and thus it is useful to consider the metallurgy of structural metals to understand the effects of construction processes on their properties.

The manufacture and use of metals for the construction of structures involves changing the material from its natural solid state at normal operating temperatures and pressures to a liquid state. This subjects the metal to structural, dimensional, and compositional changes. As a liquid metal is allowed to cool, the atoms lose energy and therefore the freedom of movement evident in the liquid state. The formation of a solid from a liquid is a process in which atoms assume a relatively rigid and regular arrangement with respect to one another. If this arrangement is geometric, it is called crystalline and the atomic pattern is called a lattice. All metals and metal alloys used in hull construction are crystalline in the solid state.

The arrangement of atoms in a solid metal can take a number of forms. These forms can be conveniently described by examining a unit cell of atoms, which when repeated successively in all three dimensions, forms a crystal.[1] The most common unit cell of metals normally used in shipbuilding is cubic and may be either body centered or face centered (see Figure 4-1). The body-centered cubic lattice, composed of an atom at each corner of the cube and one in the center of the cube, is the arrangement of chromium, tungsten, and

molybdenum. Aluminum, copper, and nickel are face-centered cubes, with an atom at each corner of the cube and one at the center of each face. Iron is unique among the common structural metals, in that it transforms from face-centered cubic to body-centered cubic during slow cooling. This transformation occurs at 1670°F (910°C).

The crystal lattice structure just described is for single-element crystals. The presence of more than one element alters the situation in one of two ways. Atoms of a second element can simply take the place of the first within the same basic lattice structure or they may tend to locate at points in between the other atoms (interstices) in the lattice. The former structure is called a substitutional solid solution and the latter an interstitial solid solution. Nickel commonly forms a substitutional solid solution with iron, while carbon, hydrogen, and nitrogen commonly form interstitial solid solutions with iron. A number of variables control the type of solid solution formed, but similar atomic size and possession of the same lattice structure in a pure form will often produce a substitutional solid solution.

The mechanism of the formation of a solid metal from a liquid is quite complex. Metals commonly experience supercooling, or cooling below the freezing point, without solidifying. Therefore, there are two temperatures that define the state of a metal. These are the liquidus, above which all the metal is liquid, and the solidus, below which all the metal is solid. In between the solidus and liquidus temperatures, the metal is partly liquid and partly solid. These temperatures are a function of the composition of the metal. Solidification occurs by nucleation, formation around a solid nucleus, and grain growth. The first solid crystals in a molten metal will form at points that are slightly cooler than average (below the liquidus temperature) and where accidental groupings of atoms favor solidification. The first crystals are called

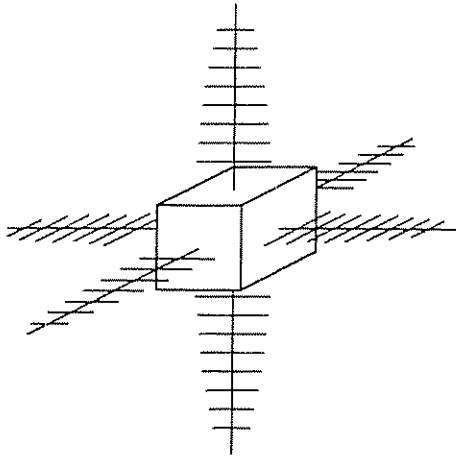


Fig 4-2 Dendritic crystal growth schematic.

nuclei and act as seeds for further solidification. Small solid impurities may provide the starting points for the nuclei.

Crystals grow by the joining of atoms to those already in the lattice structure. The growth proceeds preferentially in certain directions, since atoms can attach themselves to other atoms on some planes of the lattice more readily than on other planes. Preferential growth is perpendicular to the faces of the existing cube. The result of this preferential growth is a treelike structure composed of branches at right angles to one another (see Figure 4-2). This type of crystal is called a dendrite. As growth continues, the branches become larger and thicker and the spaces between the branches are filled by the solidifying liquid. Random orientation of the axes of different crystals results in the formation of many crystals. These crystals come into mutual contact at grain boundaries, where they are held together by atomic attractive forces (see Figure 4-3). The process of solidification, including crystal formation and grain growth, has a significant impact on the material's mechanical properties.

1.2 Phase Diagram of Steel

Metal alloys are metals formed by the combination of two or more elements. They behave

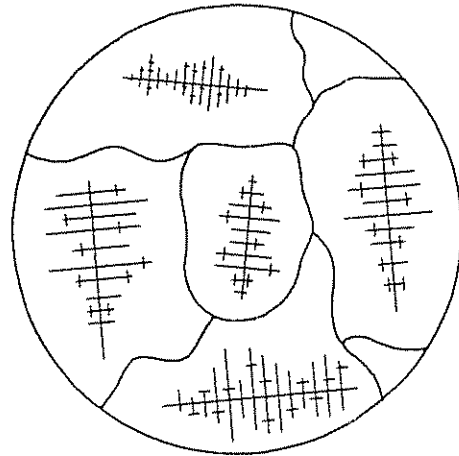


Fig 4-3 Grain boundaries of dendritic crystals

differently from pure metals when solidifying. They also have considerably different mechanical properties, which affects their use. The major controlling variables are the composition of the alloys, their temperature, and the mechanical or thermal treatments that may have been used in their manufacture. Basic information concerning the equilibrium temperature and composition of an alloy can best be presented in a phase diagram. The phase diagram is a plot of temperature versus composition of the alloy. Phase diagrams are not theoretically predicted, but are rather the result of laboratory investigation. This experimentation involves a determination of the melting and freezing point for various alloy compositions, or determination of a plot of the liquidus and solidus curves as a function of composition. For any alloy, there is one composition that will freeze (solidify) at a lower temperature than any other alloy. This alloy with the lowest melting point is called a eutectic.

Since steel is the primary metal alloy used in hull construction, a detailed review of its phase diagram will be presented. Pure iron is a relatively weak and ductile metal and is rarely used in structural applications. The addition of small amounts of carbon (and perhaps other elements) produces steel, with

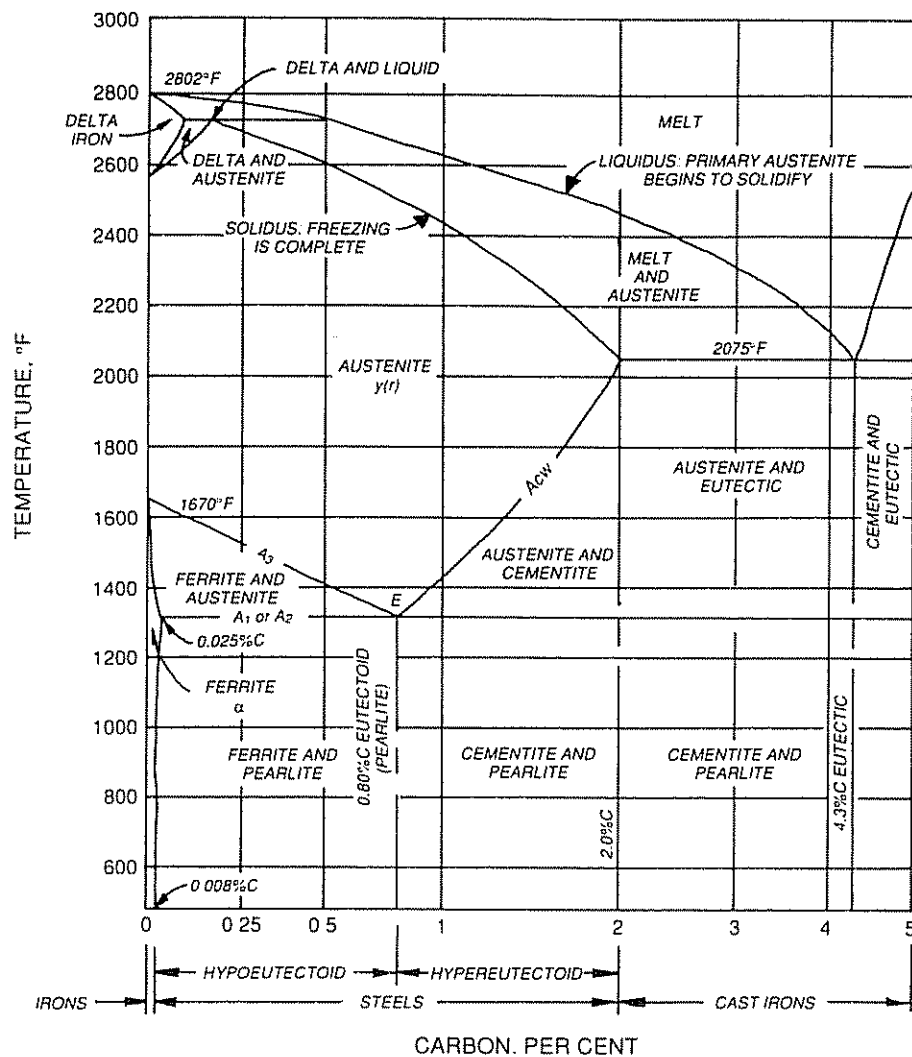


Fig 4-4. Iron/iron carbide phase diagram

considerably more favorable mechanical properties that have resulted in its becoming the most important engineering material. Since carbon is the major alloying element, the iron/iron carbide phase diagram will be considered (see Figure 4-4).

Carbon up to 2.0 percent goes into solid solution in iron. As is indicated in Figure 4-4, steel is iron with a possible maximum content of 2 percent carbon. The solidification of steel takes place at temperatures between the liquidus and solidus lines in Figure 4-4. The eutectic alloy, i.e., the alloy with the lowest

melting point, contains 4.3 percent carbon and melts at 2075°F. This alloy is a cast iron and is not used as a structural material in shipbuilding. Steel also undergoes phase changes at temperatures below the lowest melting point. These changes take place in solid steel and have important implications for its mechanical properties.

Pure iron exists in three solid phases, including alpha iron from room temperature to 1670°F, gamma iron from 1670°F to 2550°F, and delta iron from 2550°F to the melting point of 2800°F. Alpha and delta iron are

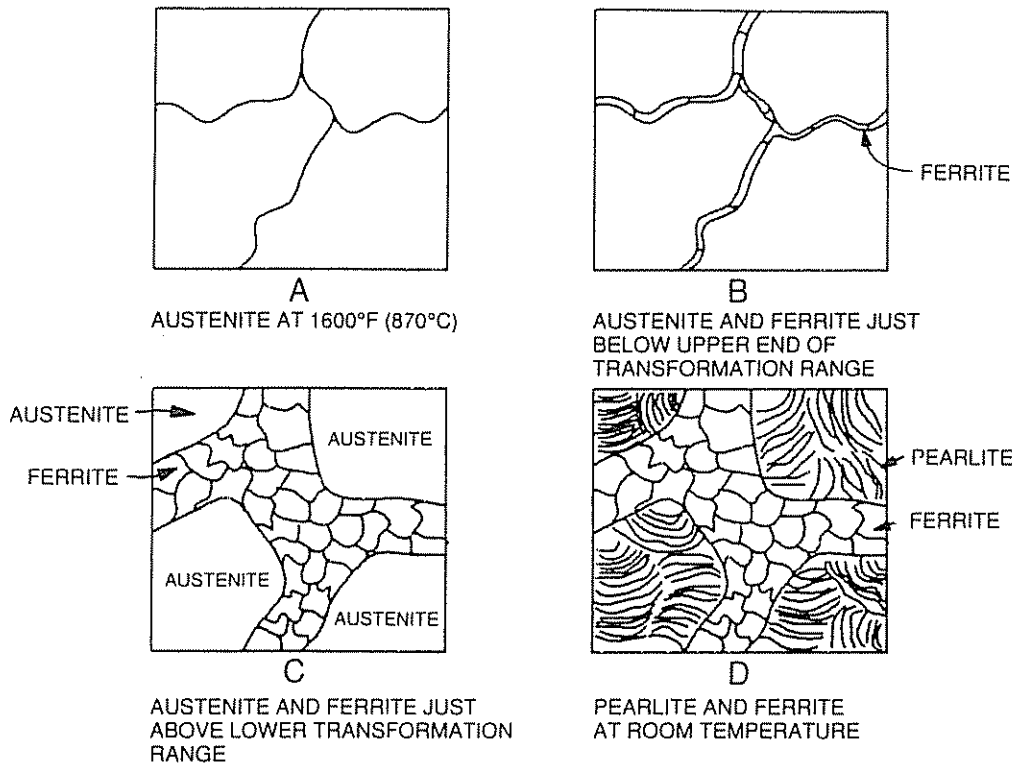


Fig. 4-5. Structural changes in 0.40% carbon steel during slow cooling.

body-centered cubic crystals, while gamma iron is face-centered cubic. Solid steel, as it is cooled from the solidus temperature, takes on one of three possible phases: austenite, ferrite, or cementite. At high temperatures (see Figure 4-4), solid steel is austenitic, a solid solution of carbon in gamma iron. As cooling continues in alloys of less than 0.8 percent carbon, the solid solution forms crystals of alpha iron containing about 0.02 percent dissolved carbon. The remaining gamma iron becomes enriched in carbon (up to 0.8 percent) and, upon cooling, transforms to a structure made up of a mixture of alpha iron and iron carbide crystals (see Figure 4-5). In steels of greater than 0.8 percent carbon, iron carbide crystals appear initially. The remaining gamma iron drops in carbon content (down to 0.8 percent) and transforms to the mixture of alpha iron and iron carbide crystals. The alpha iron containing about 0.02 percent dissolved carbon is called ferrite, the iron car-

bide is called cementite, and the mixture of ferrite and cementite is called pearlite. Pearlite is actually composed of alternating thin plates of ferrite and cementite.

The solidification process depicted in Figure 4-4 and described above occurs during slow cooling. The solid phase transformations are accompanied by volume changes. Deviation from slow cooling produces changes in grain size and grain growth. The mechanical properties of the steel can be controlled and altered by varying the cooling process. Rapid cooling of austenite can result in the suppression of the equilibrium condition for the formation of ferrite or cementite. The result can be described as a supersaturated solution of carbon in ferrite. This solution is called martensite, the essential constituent of hardened steels. The presence of other elements in addition to carbon can also precipitate the formation of martensite in steel. A third mixture of ferrite and cementite (in addition to

pearlite and martensite) can be formed. This mixture, called bainite, has properties between pearlite and martensite and is generally formed at cooling speeds between those for pearlite and martensite.

Steels can generally be subdivided into three types: pearlitic, martensitic, and austenitic. Pearlitic steels, or mild steels, have valuable properties and are generally easy to produce, handle, and weld. Martensitic steels are produced by processes that include quenching and generally tempering. They may also have additional alloying elements. These steels are the higher-strength steels, having mechanical properties that are superior to the pearlitic steels. Welding processes, however, are more complicated for martensitic steels in order to prevent deterioration of these properties. A third general class of steels, the austenitic steels, are made by including relatively large amounts of alloying elements, such as nickel and manganese. These steels, which include stainless steels, have valuable corrosion-resistance properties, but also require special welding procedures.

1.3. Properties of Steel

The great value of steel as a structural metal is based on certain properties. These can be considered in four categories:

- strength and ductility
- fracture toughness
- fatigue strength
- corrosion resistance

These properties are controlled by the composition and production processes of the steels, and may affect their welding and handling requirements

1.3.2 Strength and Ductility The strength of a metal is commonly reported in a stress-strain curve, such as the one shown in Figure 4-6. The yield strength is measured at some arbitrary amount of permanent plastic strain, or

at the point at which plastic deformation occurs with no increase in load. When such a point exists, it is called the yield point. Ductility is commonly given either by a percent elongation or by a percent reduction in area. Both the stress-strain curve and the two ductility measures are determined from a standard tension test. This test involves applying a uniaxial load to a smooth specimen in order to produce extensive plastic flow and eventually a ductile shear mode fracture. As their name indicates, the high-strength steels (with a microstructure of martensite and bainite) have higher yield strength and better ductility characteristics than the mild steels (made up of ferrite and pearlite).

1.3.3. Notch Toughness In addition to failure following plastic flow, steel is susceptible to brittle fracture, which is preceded by no readily apparent plastic flow. Brittle fractures also commonly propagate at high speeds. Some totally welded steel ships suffered serious brittle-fracture failures during World War II, and an extensive body of research into this phenomenon was subsequently developed. Brittle fractures can be caused by several factors, including temperature, strain rate, and state of stress (notch and size effects). Since low temperatures are associated with brittle fracture, the other factors are accounted for using a transition temperature approach. This approach is based on determination of an equivalent temperature at which the fracture mechanism changes from ductile to brittle.

Brittle fracture or notch toughness characteristics are determined using the Charpy V-notch test. This test involves the application of a bending load to a test specimen that has a V-notch in it. The Charpy V-notch impact value, usually expressed in foot-pounds, is the load required to fracture the test specimen.

An alternate technique for brittle fracture or notch toughness analysis is common-

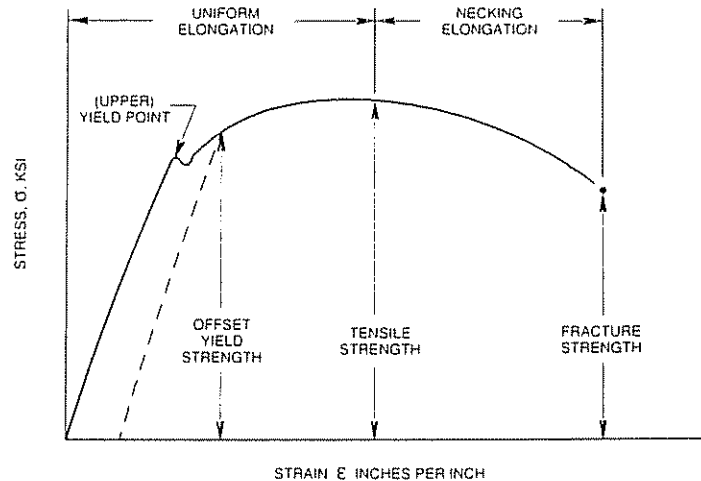


Fig 4-6. Stress-strain curve.

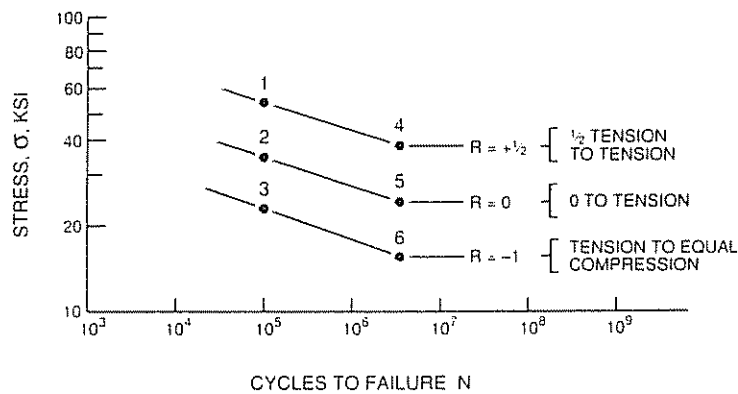


Fig 4-7 S-N plot of fatigue test results

ly employed for high-strength steels. This technique, called the fracture mechanics approach, uses the linear theory of elasticity to provide an alternate fracture criterion in terms of a stress intensity factor. The stress intensity factor is related to applied stress and flaw size. This factor must be determined experimentally for a given structure. Once determined, the stress intensity factor can be used to estimate the combination of tensile stress and flaw size at which a structure can be safely operated. The fracture mechanics approach is required by the US Navy for damage tolerance design of high-performance ships.

1 3.4. Fatigue Strength The stress that a metal can resist without failure decreases with an increase in the number of times the stress is applied. Three factors are required to initiate fatigue failure. These are sufficiently high tensile stress, sufficiently high fluctuation in the applied stress, and a large enough number of cycles of stress application. Fatigue strength is generally reported in an S-N plot, or stress versus cycles to failure on logarithmic scales (see Figure 4-7).

1 3.5. Corrosion Resistance An additional important property of steels to be used in

corrosive environments is resistance to corrosion and the effect of corrosion on strength. Both mild steels and high-strength steels are subject to corrosion and are likely to suffer strength reductions as a result of corrosion. The austenitic steels (stainless steels), designed primarily for corrosion resistance, operate by the formation of a passive film or oxide on the surface that retards further corrosion. The mechanism of corrosion and corrosion-prevention measures for mild and high-strength steels will be discussed in more detail later in this chapter.

1.4 Types of Shipbuilding Steel

Most steel used in merchant shipbuilding is low, carbon, mild, or ordinary-strength steel. Higher, carbon and other alloy steels are also used. These steels are used because of improved properties compared to mild steel, such as greater strength, better corrosion resistance, and higher notch toughness. The properties of these various grades of steel are obtained through variation in the composition of the steel and in the manufacturing processes. Structural steels used for commercial construction in the United States are certified by the American Bureau of Shipping (ABS). The various grades of mild steel are listed in Table 4-1, taken from ABS Rules. [2] These rules specify the manufacturing process, chemical composition, tensile strength, Charpy V-notch test results, and heat treatment. ABS requirements in these same categories for high-strength steels are listed in Table 4-2.

High-strength steels have been developed specifically for use in naval construction. In general, these steels, called HY-80, HY-100, and HY-130, have strength properties in excess of the commercial grade high-strength steels. Table 4-3 provides some of the properties of these and other grades of high-strength steels available for use in shipbuilding. [3]

The major considerations in the choice of steels for shipbuilding are properties of the steel, ease of use in construction, avail-

ability, and cost. Mild steel is predominant in commercial shipbuilding because of its relatively low cost, ready availability, and ease of welding. The higher-strength steels find considerable application in naval ship construction due to design constraints, especially the need to control weight without reducing strength.

The primary consideration in ease of use is weldability. The choice of welding electrode is critical in any welding process. The standard goal is to obtain a weld with equivalent strength characteristics to the base metal. Since minor flaws are likely to occur in production welding, welds are often designed and welding electrodes chosen that will produce welds with properties in excess of those of the base metal. In addition to the proper choice of electrode, preheating of the base metal is often required, especially when welding high-strength steels.

In order to reduce the need for strict welding process controls and therefore to reduce the costs associated with welding HY-80, research has been conducted to develop new, high-strength steels.[4] The result of this research is a ferritic steel, called high-strength low-alloy (HSLA) steel. This steel is substantially replacing HY-80, since it possesses equivalent properties but can be welded in a manner similar to mild steel. Use of HSLA steel for naval construction was initiated in 1984.

1.5 Aluminum and Aluminum Alloys

Aluminum has found increased application as a shipbuilding metal as a result of its high strength-to-weight ratio compared to steel. Although its use for hulls has been limited, aluminum superstructures are quite common for both naval and merchant ship construction. All aluminum vessels are primarily in the smaller sizes, such as fish boats, pleasure boats, small passenger boats, gunboats, and hydrofoils. Most shipbuilding aluminum is alloyed, commonly with manganese, magne-

Table 4-1. Requirements for ordinary-strength hull structural steel

Grades	A	B	D	E	DS	CS
Deoxidation	Any method except rimmed steel for plates over 12.5 mm (0.5 in.)	Any method except rimmed steel	Fully killed fine-grain practice ² (See 43.3.2d)	Fully killed fine-grain practice (See 43.3.2d)	Fully killed fine-grain practice (See 43.3.2d)	Fully killed fine-grain practice (See 43.3.2d)
Chemical Composition (Ladle Analysis)	For all grades exclusive of Grade A shapes and bars the carbon content +1/6 of the manganese content is not to exceed 0.40%. The upper limit of manganese may be exceeded up to a maximum of 1.65% provided this condition is satisfied					
Carbon %	0.23 max ¹	0.21 max	0.21 max	0.18 max	0.16 max	0.16 max
Manganese %	2.5x carbon min for plates over 12.5 mm (0.5 in.)	0.80–1.10 min. for fully killed or cold flanging	0.70–1.35 min. for thickness 25 mm (1.0 in.) and under	0.70–1.35	1.00–1.35	1.00–1.35
Phosphorus %	0.04 max	0.04 max	0.04 max	0.04 max	0.04 max	0.04 max
Sulphur %	0.04 max	0.04 max	0.04 max	0.04 max	0.04 max	0.04 max
Silicon %		0.35 max	0.10–0.35	0.10–0.35	0.10–0.35	0.10–0.35
Tensile Test						
Tensile strength	For all Grades: 41–50 kg/mm ² (58,000–71,000 psi); for Grade A shapes 41–56 kg/mm ² (58,000–80,000 psi) For cold flanging quality: 39–46 kg/mm ² (55,000–65,000 psi)					
Yield Point, min	For all Grades: 24 kg/mm ² (34,000 psi); for Grade A over 25.0 mm (1.0 in.) in thickness 23 kg/mm ² (32,000 psi) For cold flanging quality: 21 kg/mm ² (30,000 psi)					
Elongation, min.	For all Grades: 21% in 200 mm (8 in.) (See 43.3.4d and 43.3.4e) or 24% in 50 mm (2 in.) (for specimen, see Figure 43.2) or 22% in 5.65 $\sqrt{A}$ (A equals cross-sectional area of test specimen). For cold flanging quality: 23% min in 200 mm (8 in.)					
Impact Test Charpy V-Notch						
Temperature		0°C (32°F) Over 25 mm (1.0 in.)	–10°C (14°F)	–40°C (–40°F)		
Energy avg. min						
Longitudinal Specimens		2.8 kg-m (20 ft-lbs)	2.8 kg-m (20 ft-lbs)	2.8 kg-m (20 ft-lbs)		
Transverse Specimens		2.0 kg-m (14 ft-lbs)	2.0 kg-m (14 ft-lbs)	2.0 kg-m (14 ft-lbs)		
No. of Specimens		3 from each 50 tons	3 from each 50 tons ³	3 from each plate		
Heat Treatment			Normalized over 35 mm (1.375 in.) thick ⁴	Normalized		Normalized
Marking	$\frac{AB}{A}$	$\frac{AB}{B}$	$\frac{AB^5}{D}$	$\frac{AB}{E}$	$\frac{AB}{DS}$	$\frac{AB}{CS}$

Notes

- 1 A maximum carbon content of 0.26% is acceptable for Grade A plates equal to or less than 12.5 mm (0.5 in.) and all thicknesses of Grade A shapes
- 2 Grade D may be furnished semi-killed in thickness up to 35 mm (1.375 in.) provided steel above 25.0 mm (1.00 in.) in thickness is normalized. In this case the requirements relative to minimum Si & Al contents and fine grain prac-

- 3 Impact tests are not required for normalized Grade D steel when furnished fully killed fine grain practice
- 4 Control rolling of Grade D steel may be specially considered as a substitute for normalizing in which case impact tests are required for each 25 tons of material in the heat
- 5 Grade D hull steel which is normalized or controlled rolled in accordance with Note 4 is to be stamped $\frac{AB}{DS}$

Table 4-2. Requirements for higher-strength hull structural steel

Process of Manufacture: Open Hearth, Basic Oxygen or Electric Furnace

Grades ¹	AH32	DH32	EH32	AH36	DH36	EH36
Deoxidation	Semi-killed or killed ³	Killed, fine grain practice ⁵	Killed, fine grain practice ⁵	Semi-killed or killed ³	Killed, fine grain practice ⁵	Killed, fine grain practice ⁵
Chemical Composition for All Grades (Ladle Analysis)						
Carbon, %	0.18 max.					
Manganese, % ²	0.90–1.60					
Phosphorus, %	0.04 max.					
Sulphur, %	0.04 max.					
Silicon, % ³	0.10–0.50					
Nickel, %	0.40 max.	These elements need not be reported on the mill sheet unless intentionally added.				
Chromium, %	0.25 max.					
Molybdenum, %	0.08 max.					
Copper, %	0.35 max.					
Columbium, % (Niobium)	0.05 max.					
Vanadium, %	0.10 max.					
Tensile Test						
Tensile Strength	48–60 kg/mm ² ; 68,000–85,000 psi		50–63 kg/mm ² ; 71,000–90,000 psi			
Yield Point, min	32 kg/mm ² ; 45,500 psi		36 kg/mm ² ; 51,000 psi			
Elongation, min	For All Grades: 19% in 200 mm (8 in.) or 22% in 50 mm (2 in.) (for specimen in Figure 43.2) or 20% in 5.65 $\sqrt{A}$ (A equals area of test specimen).					
Heat Treatment: See Table 43.4						
Impact Test Charpy V-Notch						
Temperature	None Required	–20°C (–4°F)	–40°C (–40°F)	None Required	–20°C (–4°F)	–40°C (–40°F)
Energy, avg. min.						
Longitudinal Specimens		3.5 kg-m (25 ft-lb) ⁶	3.5 kg-m (25 ft-lb)		3.5 kg-m (25 ft-lb) ⁶	3.5 kg-m (25 ft-lb)
or Transverse Specimens		2.4 kg-m (17 ft-lb) ⁶	2.4 kg-m (17 ft-lb)		2.4 kg-m (17 ft-lb) ⁶	2.4 kg-m (17 ft-lb)
No. of Specimens		3 from each 40 tons	3 from each plate		3 from each 40 tons	3 from each plate
Marking	AB/AH32	AB/DH32 ⁷	AB/EH32	AB/AH36	AB/DH 36 ⁷	AB/EH36

Notes

- The numbers following the Grade designation indicate the yield point to which the steel is ordered and produced in kg/mm². A yield point of 32 kg/mm² is equivalent to 45,500 psi and a yield point of 36 kg/mm² is equivalent to 51,000 psi.
- Grade AH 12.5 mm (0.50 in.) and under in thickness may have a minimum manganese content of 0.70%.
- Grade AH to 12.5 mm (0.50 in.) inclusive may be semi-killed in which case the 0.10% minimum Silicon does not apply.

- Unless otherwise specially approved, Grade AH over 12.5 mm (0.50 in.) is to be killed with 0.10 to 0.50 percent Silicon.
- Grades DH and EH are to contain at least one of the grain refining elements in sufficient amount to meet the fine grain practice requirement (See 43 5 2d).
- Impact tests are not required for normalized Grade DH.
- The marking AB/DHN is to be used to denote Grade DH plates which have either been normalized or control rolled in accordance with an approved procedure.

Table 4-3. Properties of high-strength hull structural steels developed for navy ship construction

TYPE	PROPRIETARY GRADES ^a	MIL-S-16216 GR HY-80	ASTM A543 CL 1	ASTM A543 CL 2	ASTM A517-67 ^a	MIL-S-13326 CLASS 90	MIL-S-16216 GR. HY-100	MIL-S-13326 CLASS 120
MECHANICAL PROPERTIES:								
Yield Strength, psi-min	80,000	80,000	85,000	100,000	100,000	90,000	100,000	120,000
Tensile Strength, psi-min.	b	b	105,000	115,000	115,000	b	b	b
Elongation in 2-in.-percent	18	20	16	16	16	No limit spec.	18	No limit spec.
Approx. NDT range-deg F	-40 or lower	-130 or lower	-120 or lower	-90 or lower	-50 or lower	-40 or lower	-100 or lower	-20 or lower
Avail. Thickness range-in.	3/16 to 2 1/2 c	3/16 to 8	3/16 to 4	Over 4	3/16 to 2 1/2	No limit spec.	3/16 to 3	No limit spec.
Relative Cost, Dec. 1963, Ref. ABS Class "B"	2.0	3.5	3.0	3.0	2.0	2.0	3.5	3.5
Heat treatment	Q & T	Q & T	Q & T	Q & T	Q & T	Q & T	Q & T	Q & T
Weldability	Special	Special	Special below 0.21c	Special below 0.21c	Special	Special	Special	Special below 0.21c
CHEMISTRY: Ladle								
C	0.21 Max.	0.18	0.23 Max.	0.23 Max.	0.21 Max.	no	0.20	no
Mn	—	0.10-0.40	0.40 Max.	0.40 Max.	—	Chemistry Specified	0.10-0.40	Chemistry Specified
P Max ₁	0.040	0.025	0.035	0.035	0.035	—	0.025	—
S Max ₁	0.040	0.025	0.040	0.040	0.040	—	0.025	—
Si	—	0.15-0.35	0.20-0.35	0.20-0.35	—	—	0.15-0.35	—
Cr	—	1.00-1.80	1.50-2.00	1.50-2.00	—	—	1.00-1.80	—
Ni	—	2.00-3.25	2.60-3.25	3.00-4.00	—	—	2.25-3.50	—
Mo	—	0.20-0.60	0.45-0.60	0.45-0.60	—	—	0.20-0.60	—
V	—	—	0.03 Max.	0.03 Max.	—	—	—	—
Cu	—	—	—	—	—	—	—	—
Ti	—	—	—	—	—	—	—	—
Zr	—	—	—	—	—	—	—	—

a. This column includes proprietary grades individually identified by chemistry, mechanical properties, and thickness range.

b. Approximately 10,000 to 15,000 psi above yield strength.

c. Normal range available. Plates to 8-in. thick are available in some proprietary grades.

sium, silicon, and/or zinc. These alloys offer good strength, corrosion resistance, and weldability.

Like steel, welding is the common means of joining aluminum parts. Welding of aluminum is quite common in shipyards but, as with high-strength steels, a number of factors

must be considered and controlled. The major problems in welding aluminum are weld porosity, shrinkage, and distortion as a result of high heat conductivity, and loss of strength in the heat-affected zone. Careful control of the welding process is required to minimize these problems. [5]

2. Metal Processes

A large part of the production work performed at a shipyard involves the handling, straightening, cutting, forming, and joining of steel plates and steel structural sections. Most structural shipbuilding therefore involves the related processes of cutting, shaping, and welding steel. For commercial shipbuilding, steel processes are subject to review and approval by regulatory bodies (USCG) and/or classification societies (ABS). In U.S. practice, most oversight is performed by ABS, operating under a memorandum of understanding with the USCG. The ABS Rules for Building and Classing Steel Vessels [2] contains a section on the required procedures and practices of welding for hull construction and outfitting. Similar standards and requirements have been established by the U.S. Navy for naval ship construction.

2.1 Straightening of Plates and Sections

Because of the uneven cooling after rolling and the stressing that occurs in the steel mill and during handling and transportation, plates and sections arrive at the shipyard in a deformed condition. The misshapen condition makes marking and cutting difficult and causes additional stresses in the fabrication and assembly.

The operation of eliminating the distortion can be carried out with the metal either cold or hot. In the case of working with cold material, the process typically involves passing the plates between two rows of rotating rolls (see Figure 4-8). The pressure of the cen-

ter rolls produces several bends; other rolls gradually straighten the plate. The greater the distortion of the plates, and the less their thickness, the greater the number of passes that are required.

Plates that are in a hogging condition (more commonly found in thin plates or sheet metal) require additional attention because hogging causes a springing effect. This makes straightening more difficult, and roll straighteners must therefore have a large number of rolls (up to 17 for sheet metal), with one pair acting as clamps. Figure 4-9 is a diagram show-

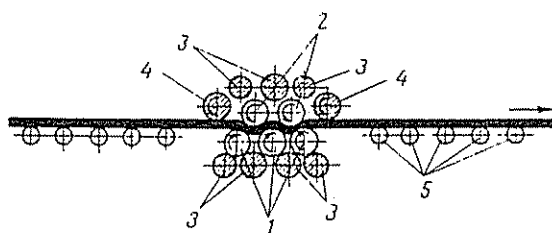


Fig. 4-8. Diagram illustrating plate being straightened in roll-straightener. 1—lower work rolls; 2—upper work rolls; 3—back-up rolls; 4—auxiliary rolls; 5—roller table.

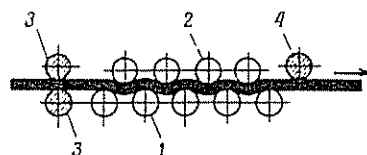


Fig. 4-9. Diagram illustrating the straightening of thin plates (sheet metal): 1—lower work rolls; 2—upper work rolls; 3—clamping rolls; 4—auxiliary roll.

ing the cross section of the rolls that might be used to straighten sheet metal.

The straightening of sections requires different methods. Small, thin sections are generally righted on an anvil. Large sections are straightened in bending presses or in straightening machines fitted with rollers. In the case of bending presses, the metal is straightened by bending it as a beam on two supports (the distance between them can be altered), with a concentrated load applied somewhere between the two supports. In the case of straightening machines, the rollers are specifically configured to the size of the material being worked.

Distortion removal using heat is performed using essentially the same methods as employed in the shaping of material during the forming process (see Sections 2.3.2 and 2-7, below).

2.2 Cutting

Steel and aluminum generally come to a shipyard in standard size plates or structural shapes. Prior to its use in shipbuilding, much of this material must be cut to required sizes and shapes. The cutting of metals in a shipyard is done by mechanical or thermal processes.

2.2.1 Mechanical Cutting Mechanical cutting primarily involves two types of machines: shears for heavier, structural steel, and saws for lighter metal, e.g., sheet metal. These mechanical devices are being used less for heavier cutting work, having been replaced by thermal cutting equipment. Heavy-duty shears (see Figure 4-10), sometimes called guillotines, may still be useful for cutting smaller shapes or improving work flow. Sheet metal is commonly cut in shops, often using band saws (see Figure 4-11).

Plates with straight edges are cut using guillotine shears (or press shears). Plates with curved edges are cut with press shears if the radius of curvature is large, or with disk shears

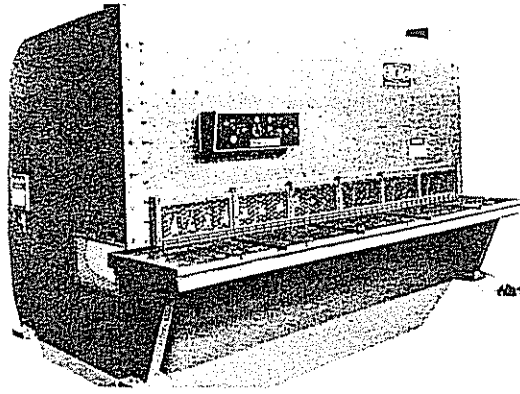


Fig 4-10 Heavy-duty shears (courtesy Chicago-Dreis and Krump).

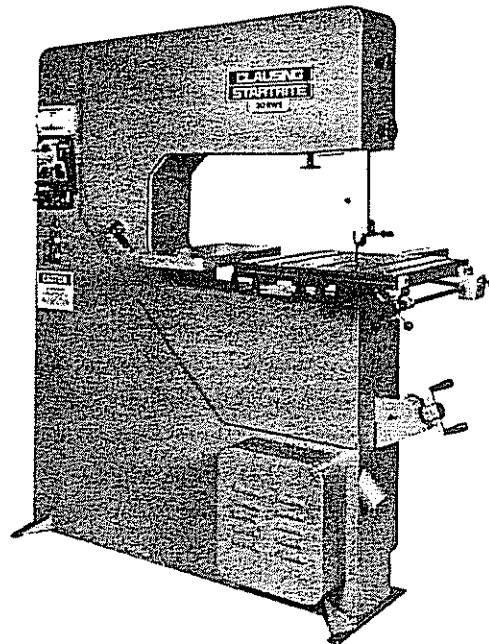


Fig 4-11. Band saw for sheet metal cutting (courtesy Clausing Startrite)

if the radius of curvature is small or if the edges are of irregular shape.

One of the advantages of mechanical cutting is that there is little distortion caused by the cut. As a result, mechanical cutting is often specified where dimensional control can be affected by the heat distortion that occurs in a thermal cut; an example would be the cutting of thin materials.

2.2.2. Thermal Cutting. There are four types of thermal cutting: oxygen (or gas) cutting, plasma arc cutting, air carbon arc cutting (sometimes called air-arc gouging), and laser beam cutting. These processes provide low-cost, precision cuts of high quality in a variety of metals. The applicability of these cutting processes to shipbuilding metals is summarized in Table 4-4.

Table 4-4. Applicability of cutting processes to materials

(To be used only as a very general guide)

Material	Oxygen Cutting	Plasma Arc Cutting	Air Carbon Arc Cutting	Laser Beam Cutting
Carbon steel	Yes	Yes	Yes	Yes
Stainless steel	Special Treatment	Yes	Yes	Yes
Cast iron	Special Treatment	Yes	Yes	Yes
Aluminum		Yes	Yes	Yes
Titanium	Special Treatment	Yes	Yes	Yes
Copper		Yes	Yes	Yes
Refractory metals		Yes	Yes	Yes

Source: *Welding Handbook*, Eighth Edition

Oxygen (gas) cutting uses a flame to rapidly oxidize (burn) the metal to form a liquid oxide, which is then blown away by the kinetic energy of the gas stream. It can be manual or automatic and both types are commonly used in shipyards. Acetylene and propane are the most common fuels used for gas cutting. The equipment for gas cutting is similar to that used for gas welding, except a burning torch is used (see Figure 4-12) instead of a welding torch. Oxygen cutting is almost always selected to cut mild steel plates up to 12 inches (300 mm) thick. Alloy steels are more difficult, and the quality of the cut in such steels depends on the alloy formulations that exist in the material. Stainless steels cannot be easily cut, but a poor quality separation can be made by introducing a flux or iron-rich

powder into the cutting stream. Titanium can be cut, but the oxidized cut surfaces must be removed before welding.

Manual oxygen cutting is common, and a worker can be trained in a short time to make satisfactory cuts. However, considerable skill is necessary to produce a cut that might be suitable for welding. Finally, the capital investment in cutting equipment is modest. Even heavy-duty, manual equipment is available for less than \$500 (1991 dollars) [6].

Equipment for mechanized equipment is more expensive, and the skills required to use this equipment are dependent on design and application. Relatively little training is needed to produce good straight cuts since all of the operation conditions can be preset using tabulated data. Considerable skill is necessary to produce shape cuts with multiple torches because of the complexity of the equipment. Equipment costs will vary dependent on the nature of the drive and control systems, the sizes of the plates to be cut, and the number of torches. A coordinated drive system with optical tracking for shape cutting will cost about \$20,000 (1991 dollars) [7].

A computer-controlled system with digital control would cost considerably more.

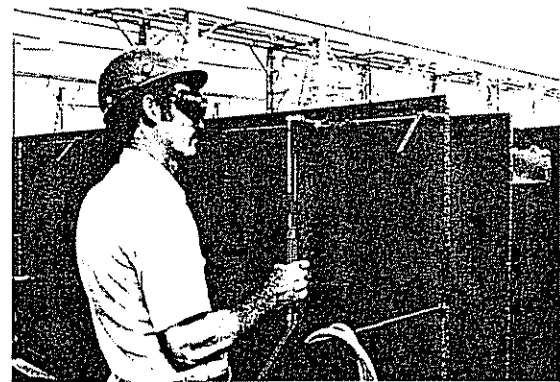


Fig. 4-12. Burning torch (courtesy Ingalls Shipbuilding)

Plasma arc cutting is the other predominant thermal cutting technique. It is an efficient process that provides excellent quality cuts and may also be used for edge preparation. Plasma arc cutting severs the metal by melting a localized area with a constricted arc and blowing away the molten metal with a high-velocity jet of ionized gas. The principle is identical to plasma arc welding, and the torch is similar. Plasma arc cutting is often done with the workpiece over or immersed in a water bath, to limit problems associated with noise, smoke, and the molten metal.

The plasma arc cutting process is versatile. All metals can be cut, and mild steel can be severed faster if the material is less than 3/4 inch thick (approximately). On the negative side, more metal is removed because the kerfs are wider and, in thick plates, the kerfs are smooth but slightly beveled. The process produces large amounts of oxides of nitrogen and is much noisier than the oxygen cutting process. Finally, the process is a consumer of electricity, and this can make it more costly if electrical energy is priced at a premium.

The air carbon arc cutting process uses an arc to melt metal which is removed by a high-velocity jet of compressed air. The depth and contour of the groove are controlled by the electrode angle, travel speed, and current. Grooves up to 5/8 inch (16 mm) deep can be made in a single pass. In severing operations, the electrode is held at a steeper angle and is directed at a point that will permit the tip of the electrode to pierce the metal being divided. This process is noisy and expensive and is thus used only for specialized operations, like removing weld defects, or severing excess metal from castings.

In laser beam cutting the source of heat is a concentrated coherent light beam. A combination of melting and evaporation provides the mechanism for removing material from the kerf. Laser beam cutting can cut all metals and certain nonmetallic materials, such

as carbon and ceramics. High-power lasers have these advantages:[8]

- The ability to cut any metal and many nonmetals regardless of hardness.
- Narrower kerf and heat-affected zone than those produced by other thermal cutting processes.
- High cutting speeds.
- Ready adaptability to computer-controlled contour cutting.

The major disadvantage of laser beam cutting is the relatively high capital cost of equipment. This factor, coupled with the rapid decrease in cutting speed as thickness increases, limits the cost effectiveness to 1/2 inch (13 mm).

One of the major automatic thermal cutting operations is the cutting of flat plate into parts for later assembly. There are two main process lanes for this activity: One is performed by a "flame profiler" and is the cutting of the plate into complicated internal parts, (e.g., inner bottom floors and deep webs). This machine is capable of cutting in any direction. The second process is performed by a "flame planer"; this machine can only cut in two directions: one straight ahead and the other at a perpendicular angle. This machine is used to perform edge preparation on the flat plate (e.g., deck plates and side shell plates).

Profile cutters or flame planers generally use one of the two cutting processes: oxygen gas or plasma arc cutting (see Figures 4-13 and 4-14).

The machines are automatically controlled, using one of numerous possible systems, including direct computer control, control by numerical tapes, and optical control. Such numerical control (N/C) cutting machines are used to cut individual plates, to cut mirror images simultaneously, to make required edge preparations, and to mark plates to establish stiffener, bulkhead, waterline,

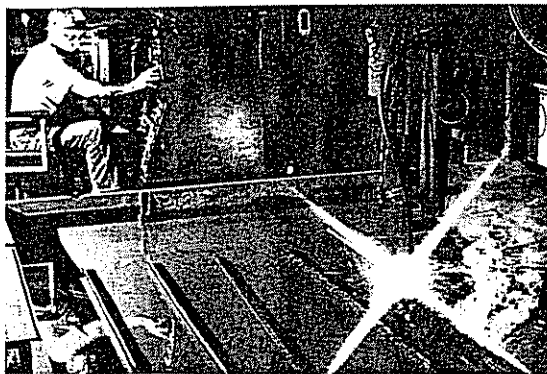


Fig 4-13. Profile cutter (courtesy Ingalls Shipbuilding).

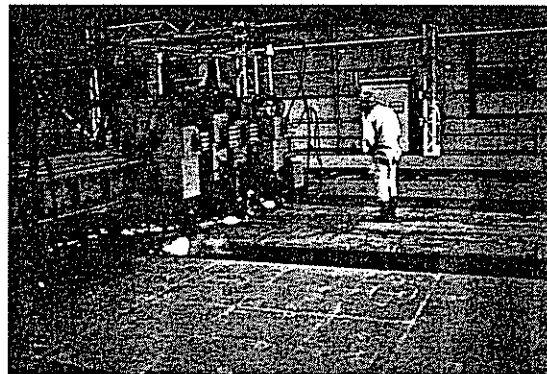


Fig 4-14. Flame planer

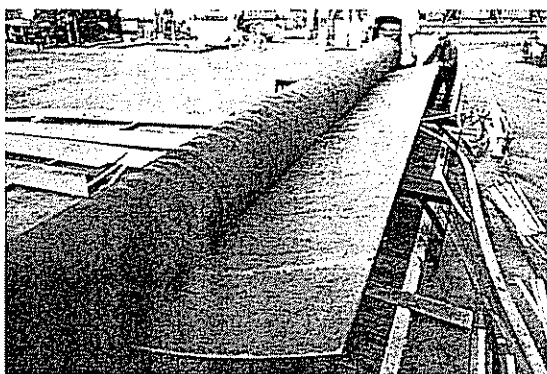


Fig 4-15(a). Rolls used for shell plate curving (courtesy Todd Pacific Shipyards, Los Angeles Division)

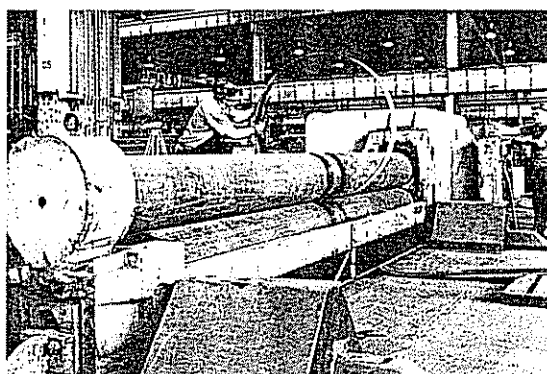


Fig 4-15(b). Rolls used for forming round components (courtesy Ingalls Shipbuilding).

section, and other required locations. (See Chapter VI for more detailed information about N/C controls, lofting, and interfaces using CAD/CAM)

2.3. Forming

Shipbuilding involves applying considerable curvature to steel plate and structural members. As in cutting, forming can be accomplished using mechanical or thermal techniques.

2.3.1. Mechanical Forming. The primary mechanical forming machines are rolls, presses, and shape benders. All these machines are hydraulically operated and commonly work with the steel cold. Rolls are primarily used

to provide cylindrical or conical curvature in shell plate. They also may be used to roll full circles for building round components such as masts and booms (see Figure 4-15). Rolls fitted with accessories are also used to make flanged plate. Presses are used to bend, straighten, and flange plate (see Figure 4-16). They are also the primary machines used to form compound curvature in plates. Compound curves are made using special die sets or can be made by knuckling. Knuckling is the process of making many slight bends in a series by repositioning the part after each bend until the desired shape is achieved. Generally, press brakes are used for shell plate work (see Figure 4-17), while gap presses are used for smaller cut parts (see Figure 4-18).



Fig. 4-16 Press used for bending plate

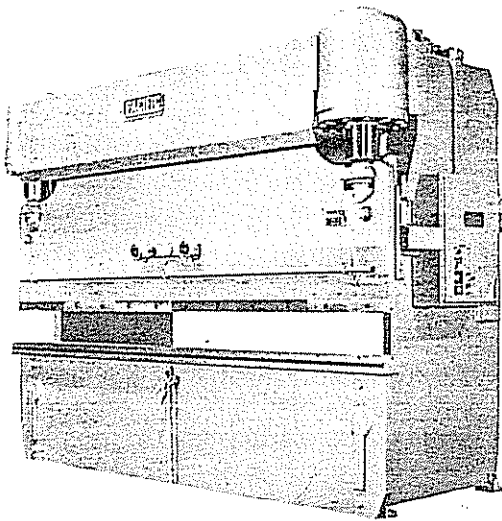


Fig. 4-17 Press brake (courtesy Pacific Press and Shear).

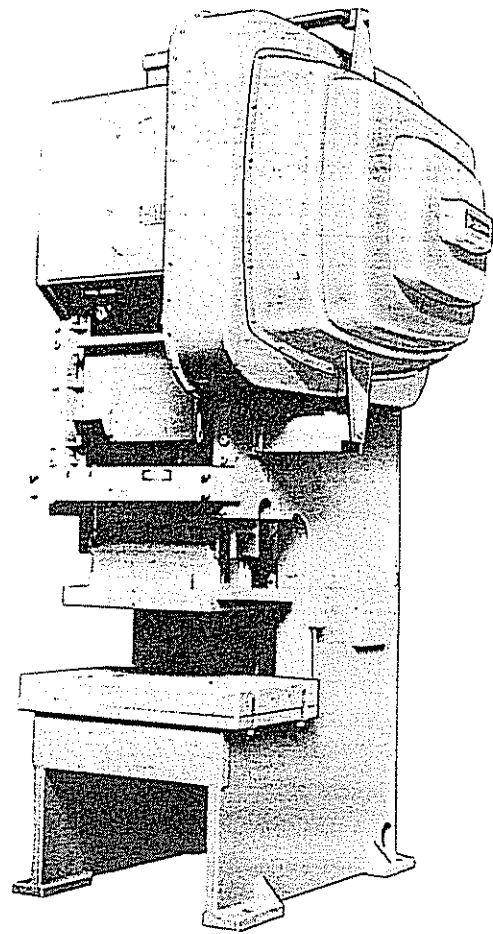


Fig. 4-18 Gap press (courtesy G W Bliss)

Structural shapes such as angles, tees, and I-beams can be bent mechanically using frame benders or beam benders (see Figure 4-19). The frame bender is used for larger bends or heavier sections, while the beam bender forms smaller sections or makes slight bends.

2 3 2. Thermal Forming (Line Heating) The fact that stress is induced in a steel plate when it is subjected to nonuniform heating is well known. When such stresses are controlled it is possible to produce strain, i.e., permanent

deformation, just as if mechanical forces were applied. Herein lies the principle of thermal forming or line heating. [9] Thermal forming may also be called flame bending.

When one side of a plate is heated along a line, it will bend upon cooling to form a slight knuckle along the line. When the heated areas are cooled with water as the heat source progresses, the bending effect is more evident. The curvature achieved is the same as if the plate were worked slightly with a press, except that some shrinkage occurs (see Figure 4-20). Such heating can be applied in all

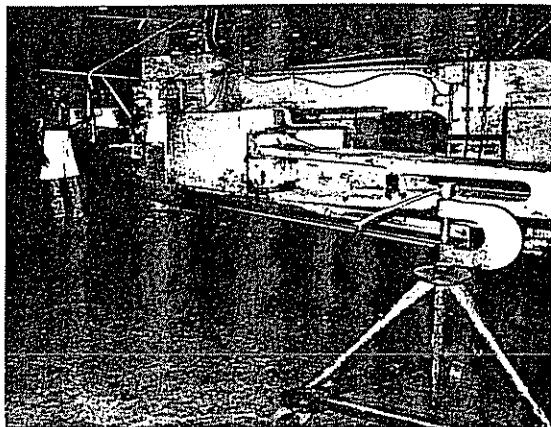


Fig. 4-19. Frame bender (courtesy Ingalls Shipbuilding)

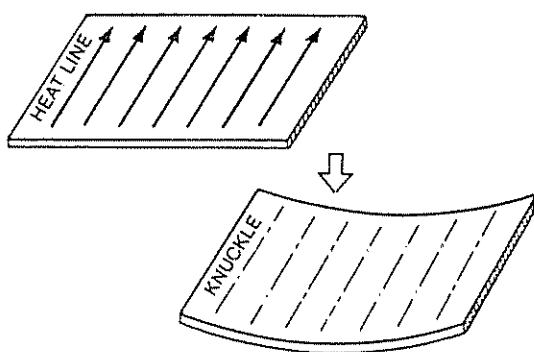


Fig. 4-20. Curvature from line heating

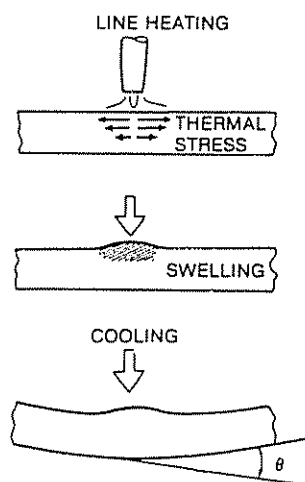


Fig. 4-21 Local reactions from line heating

directions many times over, or between or on bends formed by previous heating.

What actually happens is illustrated in Figure 4-21. Local heating creates thermal stress in a very small region. Young's Modulus and the elastic limit of the affected material both decrease with the rise in temperature. As the heat source travels, the adjacent material, even if not cooled with water, remains cool enough to resist the thermally created stress. So constrained, the heated surface swells beyond its elastic limit and therefore retains some minute deformation after cooling. During the cooling process, the bulged side surface contracts more than the other side, resulting in bending and some amount of overall shrinkage.

Thermal forming is dependent on the type of material, the plate thickness, the amount of heat applied, and the cooling process employed. The last two factors are controlled by:

- torch tip type and size
- distance between torch tip and plate
- torch travel speed
- cooling method (water or air)
- rate of applied coolant
- distance between heating center and cooling center

Among other factors, only externally applied forces which create initial stresses are significant. Considering the many types and thicknesses of materials used in shipbuilding, line heating is most practically controlled by monitoring torch travel speed. Line heating applies heat along a relatively narrow region. Thus only convergent type torch tips, such as for gas cutting, are used (see Figure 4-22). The torches used are special heating torches or gas cutting torches, modified so that their oxygen jets are inoperable.

When thermal forming is applied, plates may first be formed by a roller or press and then finished by line heating. Finishing by line heating is often necessary for accuracy purposes. Similar logic is also applied to struc-

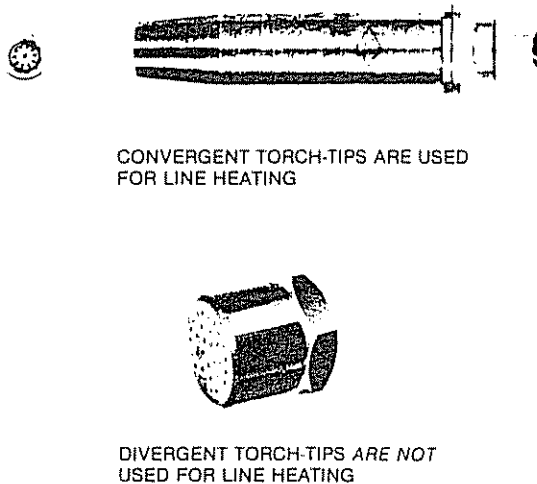


Fig 4-22. Convergent type torch tip

tural sections. Since frame bending machines are not usually designed to bend in the plane of a beam flange, line heating can be used. It is also an effective method of twisting longitudinals. Complex shapes, such as bulbous bows, are another ideal application of line heating. Figure 4-23 shows typical line heating operations.

2.4. Welding

Welding is the preferred method of joining metal for the building of ships. Although there are numerous variations, welded joints are typically either butt welds or fillet welds. [5] Butt welds join two members lying approximately in the same plane (see Figure 4-24) and fillet welds join surfaces at approximately right angles to one another (see Figure 4-25).

Shipyard welding processes are of the fusion welding type. In fusion welding, a heat source is used to melt the edges of the joint, permitting them to fuse with molten weld metal. Three metallurgical zones are thus created: the fusion zone, the unmelted heat-affected zone adjacent to the fusion zone, and the unaffected parent metal (see Figure 4-26). [10] The quality of the weld and the weld-

ment, the choice of the welding technique, and the effect of the parent metal on these characteristics can be described by considering these three zones.

Before discussing this further, it is valuable to describe the controlling characteristics of fusion welding. The fusion welding process can be described by three characteristics: heat source intensity, heat input rate per unit length of weld, and shielding methods. [10]

2.4.1 Heat Source Intensity. A minimum heat source intensity is required in order to accomplish fusion welding. As the heat source intensity increases, a point is reached at which the metal is not only melted but also partly vaporized. The pressure generated by the emergent metal vapor then depresses the pool of molten metal until a balance between this pressure and hydrostatic pressure and surface tension forces is achieved. Thus, a penetrating heat is developed, giving a fingerlike appearance. Figure 4-27 shows typical fused zone penetration profiles for various welding processes. Most welding processes generate a surface weld pool of semicircular cross section. When the penetration of a semicircular weld pool is not enough to completely fill a joint, successive weld passes may be required. Such multipass welding is depicted in Figure 4-28.

2.4.2. Heat Input Rate. The heat input rate per unit length of weld, q , can be expressed by:

$$q = hVI/v$$

where:

- v = the welding speed
- h = the proportion of arc energy transferred to the workpiece as heat
- V = the arc voltage
- I = the arc current

Heat input rate is an important variable in fusion welding, since it determines heating

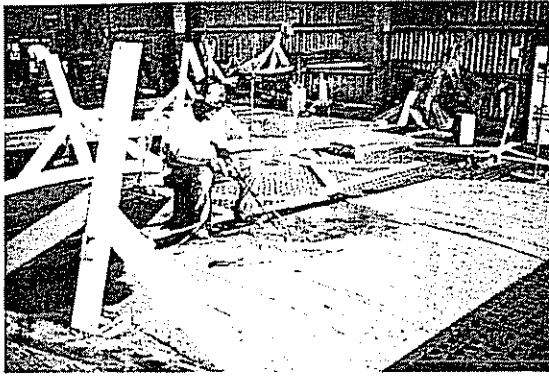


Fig 4-23(a)

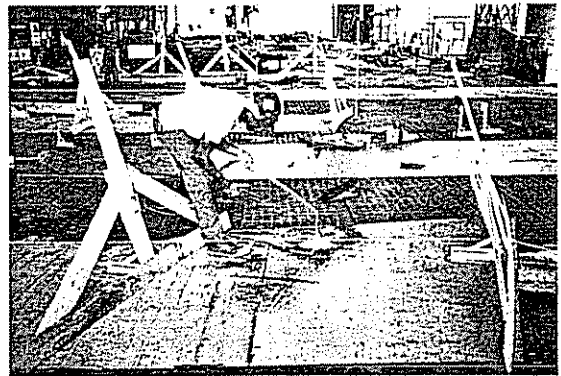


Fig 4-23(b)

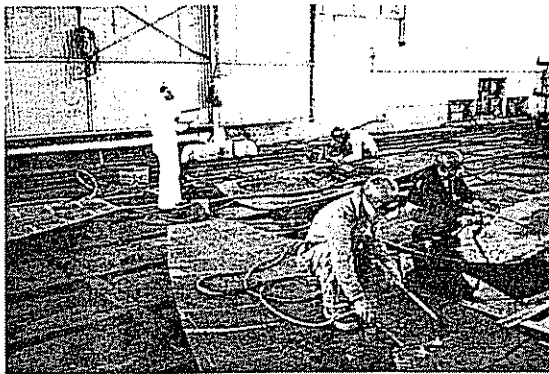


Fig 4-23(c)

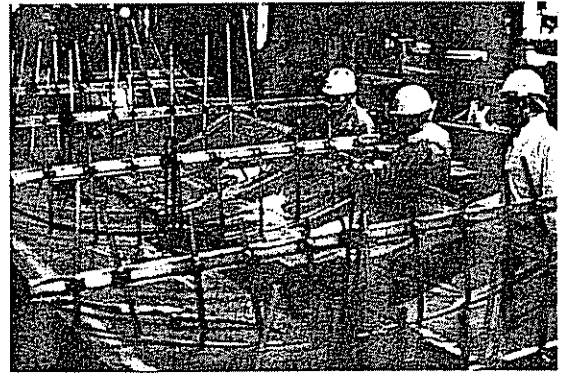


Fig 4-23(d)

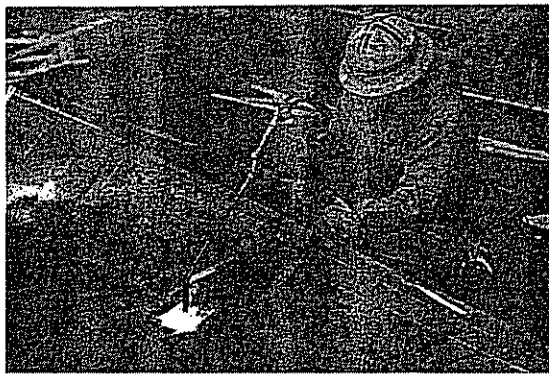


Fig 4-23(e)

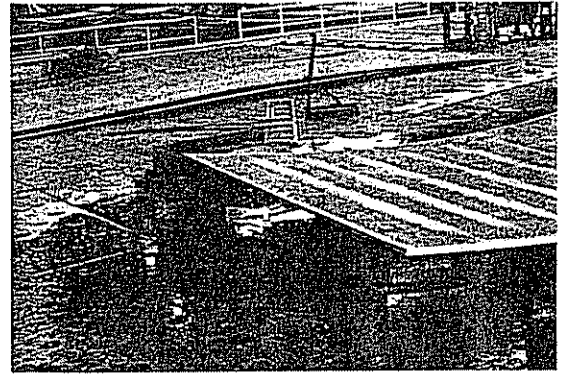


Fig. 4-23(f)

Fig 4-23. Typical line heating operations. (a) Bending plate (courtesy Avondale Shipyard) (b) Finishing plate using sight line templates (courtesy Avondale Shipyard) (c) Forming extreme curvature for a bulbous bow (courtesy Lockheed Shipbuilding) (d) Using adjustable sight line templates. (e) Producing secondary curvature in a plate that had previously been line heated (f) Use of dogs and wedges in conjunction with line heating

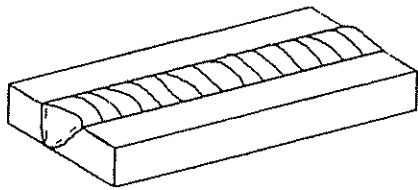


Fig 4-24. Butt weld

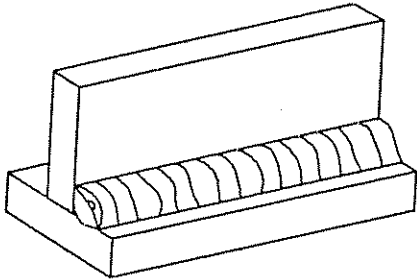


Fig 4-25 Fillet weld

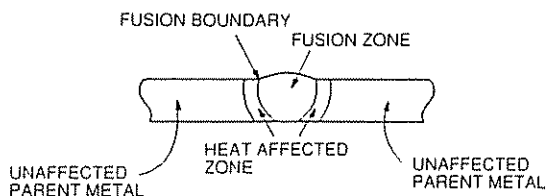


Fig 4-26 Metallurgical zones in welding

rates, cooling rates, and weld pool size. In general, the higher the heat input rate the lower the cooling rate and the larger the weld pool size. There is an inverse relationship between cooling rate and weld pool size. This is an important relationship in the welding of steel, since higher cooling rates increase the risk of hydrogen-induced cracking of a weld.

Heat input rate also directly affects grain size in the weld and the heat-affected zone. Grains in the solidifying weld metal and in the solid metal at the weld pool boundary grow coherently. Therefore, coarser grain structures will result from longer times spent above the grain-coarsening temperature of the steel being welded. Pearlitic steels suffer a deterioration of properties, particularly notch tough-

PROCESS		FUSED ZONE PROFILE
FLUX-SHIELDED ARC WELDING		
GAS-SHIELDED ARC WELDING	NORMAL CURRENT	
	HIGH CURRENT	
PLASMA	LOW CURRENT	
	HIGH CURRENT	
ELECTRON BEAM AND LASER	DEFOCUSED BEAM	
	FOCUSED BEAM	

Fig 4-27. Typical penetrations for various welding processes.

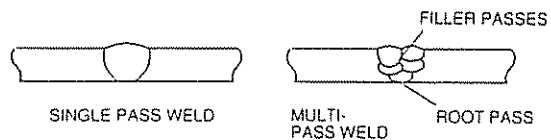


Fig 4-28. Single and multi-pass welds

ness, as grain size increases. A high heat input rate will tend to produce coarser grain structures. Consequently, a heat input rate that gives an optimum combination of grain size and cooling rate is sought.

2.4.3. Shielding. While the temperatures in the weld pool are substantially above the melting point, the drop at the tip of a fusion welding electrode may reach the boiling point. At these temperatures, reaction with oxygen and nitrogen in the atmosphere is extremely rapid. Should oxygen and nitrogen become trapped within the weld metal, embrittlement of the weld will occur. To protect against this degradation of the weld quality, shielding from the atmosphere is required.

This shielding is accomplished by means of flux or gas or a combination of the two, by physical shielding, or by evacuation of the atmosphere. In most welding processes, either flux or gas is provided for shielding. Where flux is provided, gases generated by vaporization join in a chemical reaction at the electrode tip that results in a combination of flux and gas shielding. Shielding will be discussed in the sections describing the welding processes.

2.4.4. Weld Metal Metallurgical Effects. The heat flow characteristics of a welding process determine the microstructure of the weld metal and the heat-affected zone of the parent metal. Mass flow, which includes the flow of metal from the electrode to the weld pool, the flow of metal in the weld pool, and the flow of plasma in the arc column, has less influence on the weld joint metallurgy. The laws of conservation of mass, momentum, and energy govern mass and heat flow characteristics of welds. The application of these laws to describe the welding process is discussed in numerous welding texts and is beyond the scope of this section.

Metallurgical effects that occur during welding can be considered in two categories, including gas-metal reactions and the effects of the thermal cycle on the weld metal and in the heat-affected zone. For the most part, gases other than inert gases have an unfavorable effect on weld properties. The purpose of shielding is to eliminate metallurgical damage from this cause.

The thermal cycle involves the weld metal during solidification and cooling and the heat-affected zone during heating and cooling. Heating and cooling rates are usually high, and the heated metal is subject to plastic tensile strain during cooling. These complex effects can result in unfavorable changes in the properties of the metal.

The heat-affected zone has two subregions: the high-temperature region in which major structural changes occur (such as grain

growth) and the lower-temperature region in which secondary effects occur (such as precipitation). In the high-temperature region, grain size depends primarily on the peak temperature (usually the melting point) and the time of heating and cooling (residence time). Thus the residence time is the major variable that can be controlled. Residence time is proportional to the heat input rate. Thus reducing heat input rate will reduce the generation of coarse-grained structures. The low-temperature region may be subjected to precipitation of hydrogen, which in pearlitic steels can lead to embrittlement. The precipitation of hydrogen can be controlled by proper choice of materials, welding procedure, and the weld thermal cycle. However, the relationship between the choice of materials, welding procedure, and the weld thermal cycle is sufficiently complex that there must be complete study of the system before a final decision is made on adjusting heat input.

2.5. Welding Processes

Table 4-5 presents some of the characteristics of various fusion welding processes [10]. Among the processes listed, the major categories are:

- shielded metal arc (SMA)
- flux-cored arc welding (FCAW)
- submerged arc welding (SAW)
- gas tungsten arc (GTA or TIG)
- gas metal arc (GMA or MIG)
- plasma welding (PAW)

Additional processes mentioned include:

- gas welding
- electric resistance welding
- stud welding
- electroslag and electrogas welding
- Thermit welding
- laser welding
- electron beam welding

Table 4-5 Characteristics of selected fusion welding processes

Process	Heat Source	Power Source and Polarity	Mechanics	Shielding Agent	Typical Applications		
					Metal	Thickness Range	Industrial
Shielded metal arc welding (coated electrodes SMA)	Arc	Alternating or direct current Electrode positive or negative	Short lengths of wire coated with flux. Manual operation	Slag and self-generated gas	All engineering metals and alloys except pure Cu, precious metals, low-melting and reactive metals	1 mm upwards	All fields of engineering
Submerged arc welding (SAW)	Arc	Alternating or direct current	Automatic or semi-automatic. Arc maintained in cavity of molten flux formed from granular material	Slag and self-generated gas	Carbon, low-alloy and high-alloy steels, Copper alloys	1 mm upwards (but generally over 10 mm)	Downhand or horizontal vertical joints suitable for automatic welding. Boiler pressure vessels structural steel horizontal joints in storage tanks
Gas tungsten arc (GTA) welding	Arc	Alternating current with stabilization for aluminum, magnesium and direct current electrode negative for other metals	Manual or automatic arc maintained between non-consumable tungsten electrode and work. Filler alloys, wire fed in separately	Argon, Helium or Argon/Helium mixtures	All engineering metals except Zn and Be and their alloys	1 mm to about 6 mm	Non-ferrous and alloy steel welding in all engineering fields. Root pass in pipe welds
Pulsed gas tungsten arc (GTA) welding	Arc	Direct current, electrode negative with low-frequency (1 Hz) or high-frequency (1 kHz) current modulation	Low-frequency pulse allows better control over weld pool behavior. High-frequency pulse improves arc stiffness	Argon	As above	1 mm to about 6 mm	Automatic GTA welding of tubes or tube-to-tube sheet to improve consistency of penetration or (high frequency) prevent arc wander
Flux-cored arc (FCAW)	Arc	Direct current, electrode positive	Flux is enclosed in tubular electrode of small diameter. Automatic or semi-automatic. Wire fed continuously through a gun with or without a gas shield	Slag and gas, either self-generated or from external source (normally CO ₂)	Carbon steel	1 mm upwards	Sheet metal welding general engineering
Gas metal arc (GMA) solid wire	Arc	Direct current electrode positive	As above, but in short-circuiting metal transfer mode	Argon/O ₂ Argon/CO ₂ CO ₂	Carbon and low alloy steel	1 mm upwards	Sheet metal, root pass in pipe welding positional welding
	Pulsed Arc	Direct current, electrode positive 50-100 Hz pulse superposed on low current background	Pulse detaches drop at electrode tip and permits free flight transfer at low current	Argon Argon/O ₂ Argon/CO ₂	Non-ferrous metals, Carbon low-alloy and high-alloy steels	1 mm upwards	Positional welding of relatively thin carbon or alloy steel
Plasma welding (PAW)	Arc	Direct current, electrode negative	As for gas tungsten arc except that arc forms in a chamber from which plasma is ejected through a nozzle. Improved stiffness and less power variation than GTA	Argon, Helium, Argon/Hydrogen mixtures	As above	Usually up to about 15 mm	Normally low-current application where gas tungsten arc lacks stiffness. Also used at higher currents in keyholing mode for root runs
Gas welding (OAW)	Oxyacetylene flame		Manual. Metal melted by flame and filler wire fed in separately	Gas (CO, H ₂ , CO ₂ , H ₂ O)	Carbon steel, copper, aluminum zinc and lead. Bronze welding	Sheet metal and pipe up to about 6 mm	Sheet metal welding small diameter pipe
Stud (SW)	Arc	Direct current, electrode negative for steel, positive for non-ferrous	Semi-automatic or automatic. Arc drawn between tip of stud and work until melting occurs and stud then pressed on to surface. Weld cycle controlled by timer	Self-generated gas + ceramic ferrule around weld zone	Carbon, low-alloy and high-alloy steel Aluminum, Nickel and copper alloys require individual study	Stud diameters up to about 25 mm	Shipbuilding, railway and automotive industries. Pressure vessels (for attaching insulation), furnace tubes and general engineering
Electroslag Welding (ESW)	Resistance heating of liquid slag	Alternating or direct current	Automatic. Joint set up vertically. Weld pool and slag contained by water-cooled shoes. Filler wire fed into slag pool and melted by resistance heating. No arc	Slag	Carbon, low-alloy and high-alloy steel	50 mm upward	Welding thick sections for press frames, pressure vessels shafts, etc. Foundry and steelworks applications. General engineering
Thermit (TW)	Chemical reaction	None	A mixture of metal oxide and aluminum is ignited, forming a pool of superheated liquid metal, which then flows into and fuses with the joint faces	None	Steel, austenitic Cr/Ni steel, copper, copper steel/copper joints	Normally up to 100 mm	Welding rails, copper conductors to each other and to steel
Laser (LBW)	Light beam	None	As for electron beam except different energy source	Helium	As for electron beam	Up to 10 mm	Potentially as for electron beam. Cutting non-metallic materials
Electron beam (EBW)	Electron beam	Direct current 10-200 kV, power generally in range 1/2-10 kW. Workpiece positive	Automatic welding carried out in vacuum. Beam of electrons emitted by cathode focused on joint. No metal transfer	Vacuum (10 ⁻⁴ mm Hg)	All metals except where excessive gas evolution and/or vaporization occurs	Up to about 25 mm normally but may go to 100 mm	Nuclear and aerospace industries. Welding and repair of machinery components such as gears

Each of these processes and their application in shipbuilding will be discussed in the following sections. [5,10,11]

2.5 1. Gas Welding. Gas welding employs heat generated by the burning of a gas fuel and generally uses a filler rod for the metal deposited. The most common fuel is acetylene, used in combination with oxygen (oxyacetylene gas welding). A hand-held torch directs the flame to the workpiece while simultaneously melting filler metal which is deposited on the

joint. The surface of the workpiece melts to form a molten puddle with filler material used to fill gaps or grooves. The molten metal, including filler metal, solidifies as the torch progresses along the workpiece (see Figure 4-29). The apparatus required for oxyacetylene gas welding includes a welding torch and tip, oxygen and acetylene hoses, regulators, and cylinders (see Figure 4-30).

Gas welding is comparatively slow and not suitable for use with automatic or semi-automatic equipment. Consequently, it is rare-

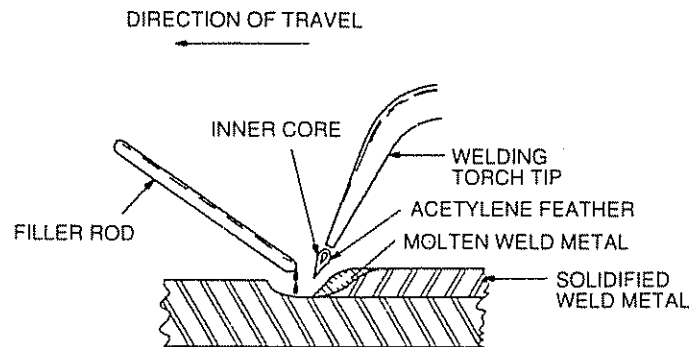


Fig 4-29 Gas welding process.

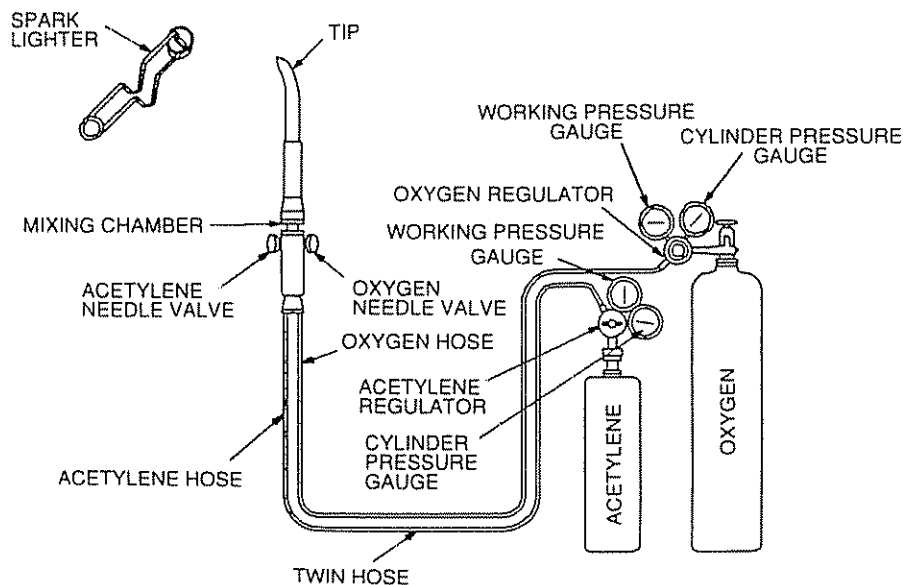


Fig 4-30 Oxyacetylene gas welding equipment

ly used for normal production welding in shipyards. The equipment is small and portable and it can be useful for welding thin plate (up to about 1/4 inch, or 7 mm), as well as for small-diameter pipe, HVAC trunks (sheet metal), electric cableways, and for brazing or soldering. Identical or similar equipment is used for cutting and forming or distortion removal, as discussed in Sections 2.2, 2.3, and 2.7.

2.5.2. Electric Resistance Welding Electric resistance welding fuses metal with the heat generated by the resistance of the workpiece to an electric current in a circuit of which the workpiece is a part. Electric resistance welding requires that the weld area be under pressure while the welding is taking place. Pressure is applied by mechanical, hydraulic, or pneumatic systems. Due to the complexity of this welding process, resistance welding operations must be automatic. Current is generated by an electrode in contact with the workpiece. The welder's primary tasks are to set the machine, including current, pressure, and travel speed, and to load and unload the work. The major application of resistance welding is to mass production systems, since setup and adjustment are time-consuming and consistent conditions need to be maintained. Therefore, shipyards

rarely use electric resistance welding except for electroslag process (see Section 2.5.4).

2.5.3. Electric Arc Welding. In electric arc welding a circuit is created between the workpiece and an electrode or wire. When the electrode or wire is held a short distance away from the workpiece, a high-temperature arc is created. This arc generates sufficient heat to melt the edges of the workpiece and the tip of the electrode or wire to produce a fusion welding system. There are a number of electric arc welding processes suitable for use in shipbuilding. All require the shielding of the weld area from the atmosphere. They may be generally subdivided into flux-shielded and gas-shielded processes (see Figure 4-31).

Flux-shielded electric arc welding processes are distinguished primarily by their manual or automatic nature and the type of electrode used. The manual process, shielded metal arc welding (SMAW), uses a consumable electrode or welding rod held in a holder and fed to the workpiece by the welder (see Figure 4-32). The electrode metal is surrounded by flux which melts as welding progresses, covering the deposited molten metal with slag and enveloping the immediate area in an atmosphere of protective gas (see Figure 4-33). Numerous electrodes are available,

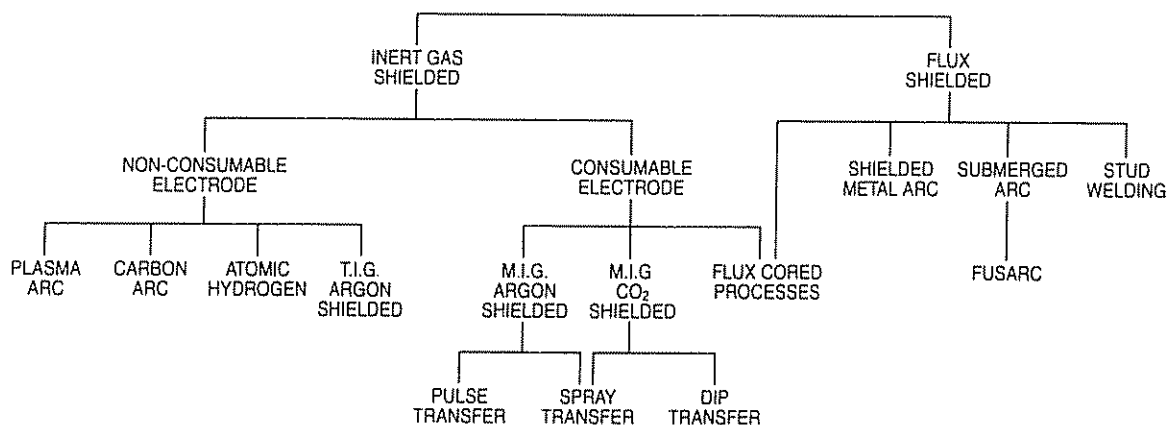


Fig 4-31. Electric arc welding processes

as classified by the American Welding Society (AWS) [11] and the American Society for Testing and Materials (ASTM). The choice of electrode is based on the specifics of the welding, i.e., the required composition and properties of the deposited weld metal. The position of the welding may also affect the choice of electrode. The flexibility of this process makes it one of the most popular in shipbuilding.

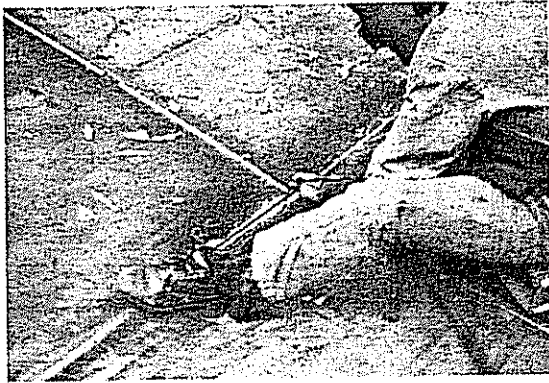


Fig 4-32. Manual shielded metal arc welding

Manual shielded metal arc welding may be used for downhand, horizontal, vertical, and overhead welding (see Figure 4-34). It may also be semiautomatic through the use of a gravity welding machine. This machine uses the weight of the electrode and holder to produce travel along the workpiece. The angle of the electrode to the workpiece can be adjusted to alter the amount of metal deposited (see Figure 4-35). Fully automatic shielded metal arc welding is also employed, using a continuously fed electrode mounted on a moving carriage (see Figure 4-36). Continuous fillet welds on both sides of stiffeners can be obtained using this type of automatic equipment. The electrode is normally a flux cored wire. Additional CO_2 shielding may be used to improve the weld quality. These automatic processes are fast and efficient and particularly useful in shipyard panel lines.

Submerged arc welding (SAW) is another flux-shielded electric arc welding process used in many shipyards. In this process, a blanket of granulated flux is deposited on the

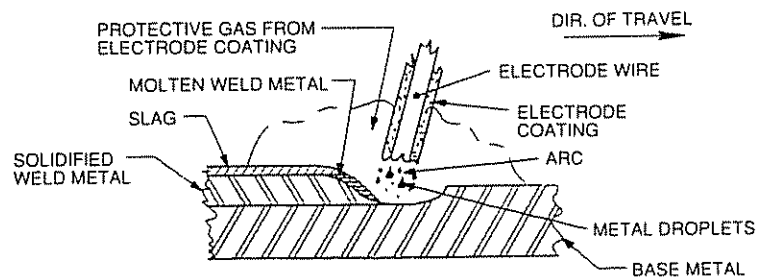


Fig. 4-33 Manual shielded metal arc welding process

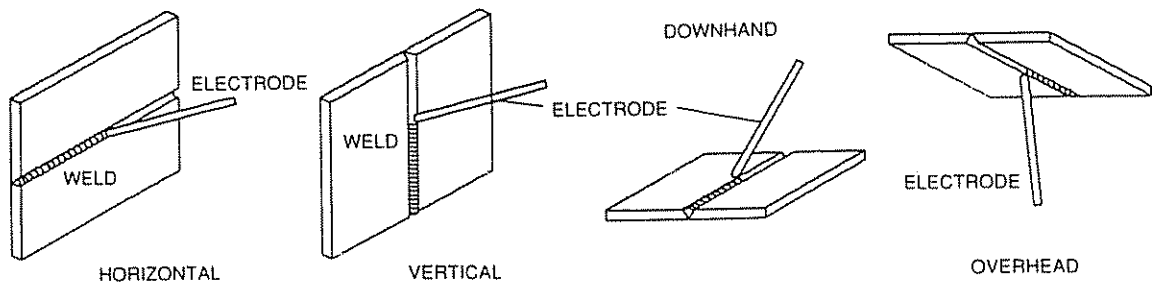


Fig 4-34. Manual shielded metal arc welding positions.

workpiece, followed by a consumable wire electrode. The arc, submerged in the blanket of flux, melts the flux to produce a protective,

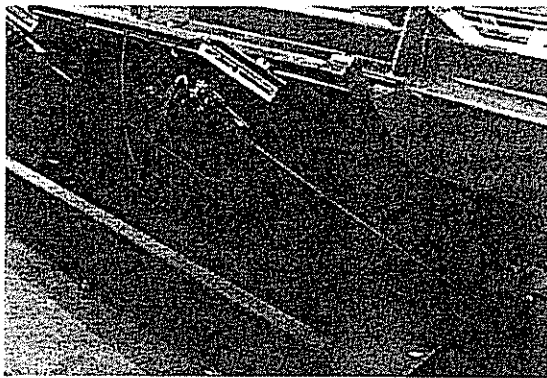


Fig. 4-35. Gravity welding machine (courtesy Total Transportation Systems).

thermally insulated molten shield for the weld zone (see Figures 4-37 and 4-38). High heat concentration permits heavy weld deposits at relatively high speeds. After welding, the molten metal is protected by a layer of fused flux, which is subsequently removed and may be recovered. Backing bars may be used, and the process may employ single- or multiple-pass welding. Submerged arc welding must be performed downhand and is ideally suited to butt welding plates together.

Stud welding is a form of electric arc welding in which the stud itself is the electrode. A stud welding gun holds the stud while the arc is formed and the plate and stud end become molten. The gun then forces the stud against the plate and the stud is welded

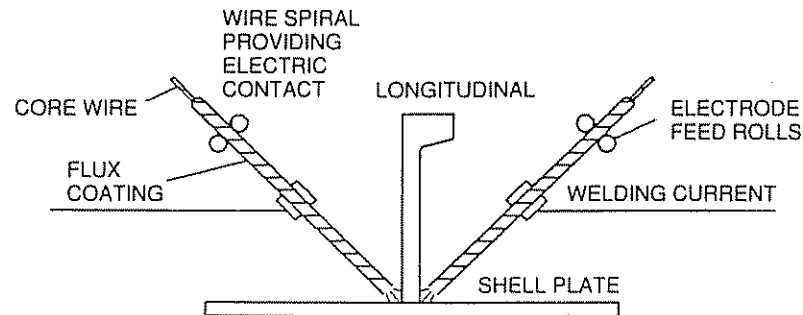


Fig. 4-36. Automatic shielded metal arc welding.

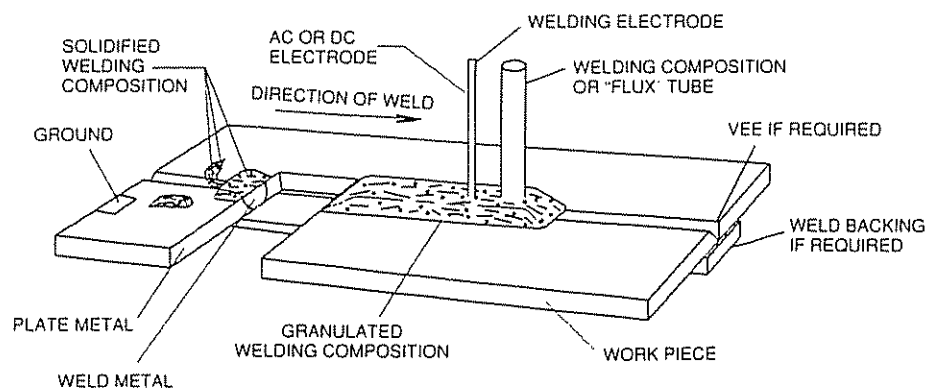


Fig. 4-37 Submerged arc welding

to the plate. Shielding is obtained by the use of a ceramic ferrule surrounding the stud (see Figure 4-39). Stud welding is a semiautomatic process commonly used in shipbuilding to facilitate installation of nonmetallic materials, such as insulation, to steel surfaces.

The second major category of electric arc welding is the gas-shielded processes. These processes use bare electrodes with an externally supplied gas shield, employing either inert, active, or a combination of inert and active gases. The first process of this type is gas tungsten arc (GTA) welding or tungsten inert gas (TIG) welding (see Figure 4-40). The arc is generated between the workpiece and a tungsten electrode which is not consumed. An inert gas, usually argon or helium, provides the shielding. Often the welding torch is provided with a water cooling system. In most cases a filler rod is externally fed to

provide filler material. Unlike most other electric arc welding processes, the arc does not transfer the filler metal, but simply melts it, resulting in a cleaner weld. GTA welding is most often employed in shipyards for welding aluminum, sheet metal, and small diameter pipes and tubes, or to deposit the first pass on a multipass weld in larger pipe.

A related welding process is called gas metal arc (GMA) welding or metal inert gas

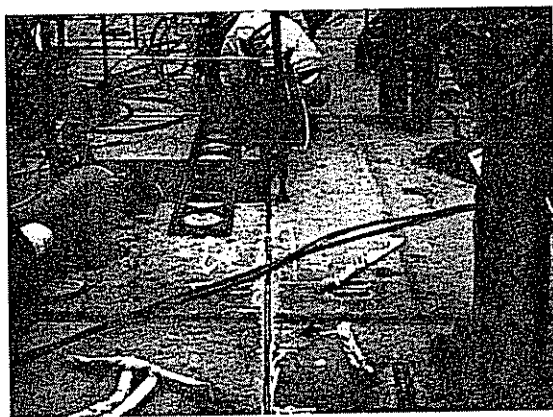


Fig. 4-38(a). Submerged arc welding, semiautomatic

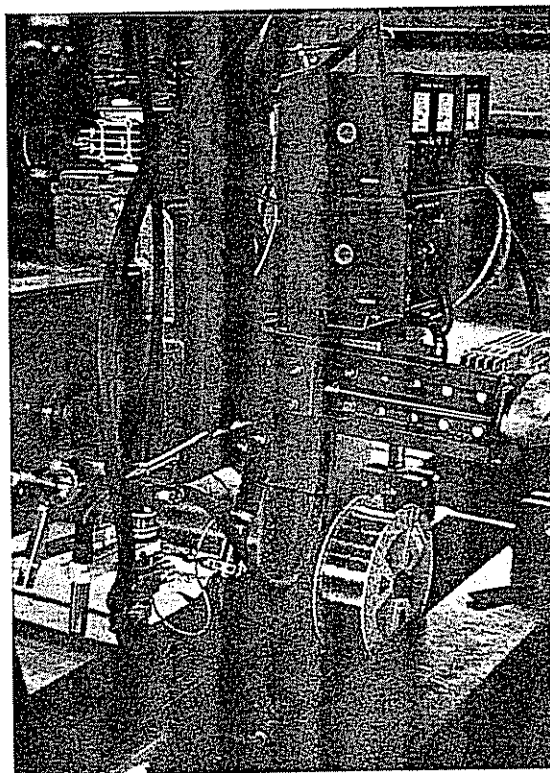


Fig. 4-38(b) Submerged arc welding, automatic equipment (courtesy Total Transportation Systems)

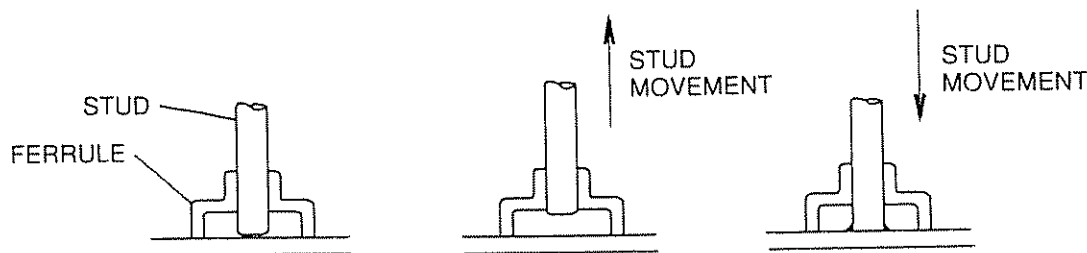


Fig 4-39 Stud welding

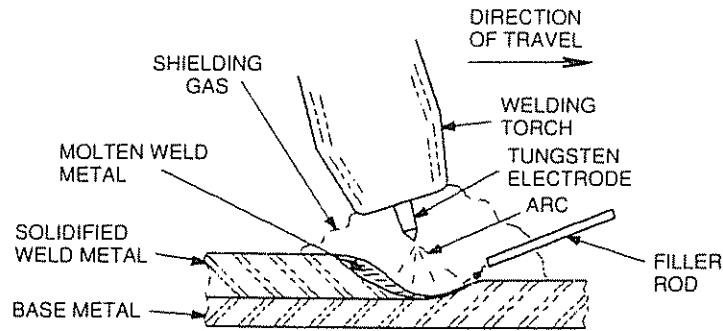


Fig 4-40. Gas tungsten arc welding.

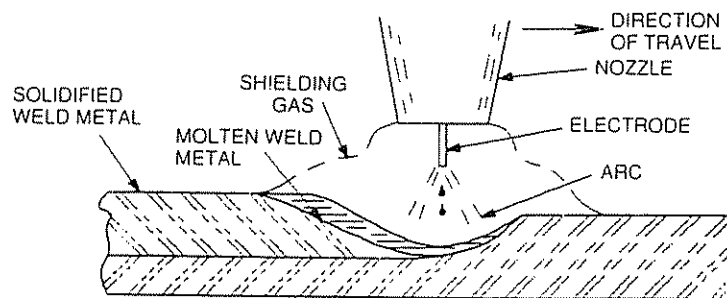


Fig 4-41. Gas metal arc welding

(MIG) welding (see Figure 4-41). GMA welding uses a consumable electrode and inert gas shielding. Generally, a wire spool provides the electrode, with argon or helium being used as the shielding gas. It was found that for welding steel, CO_2 could be used as the shielding gas to replace the more expensive argon or helium. Often, a combination of the gases is used to optimize cost and weld quality. GMA welding is generally an automatic or semiautomatic process.

The last of the inert gas welding processes is plasma arc welding (see Figure 4-42), sometimes called the plasma metal inert gas process. The plasma is an ionized stream of gas that carries the arc. It is generated by constricting the arc to pass through a small orifice in the torch. Plasma metal inert gas welding results in a more concentrated, high-temperature arc and thus permits faster

welding. Aside from the use of the orifice to accelerate the gas, plasma metal inert gas welding is identical to GTA welding, using a nonconsumable tungsten electrode and an inert gas shield. Plasma arc welding is generally manual and has had minimal use in shipbuilding.

2.5.4. Other Welding Processes. Five additional types of welding may be used in shipyards. These are electroslog, electrogas, thermit, laser, and electron beam welding. Electroslog welding transfers heat through molten slag, which melts the workpiece and the filler metal (see Figure 4-43). Although the equipment used is similar to that used for electric arc welding, the slag is maintained in a molten state by its resistance to current passing between the electrode and the workpiece, and thus it is a form of electric resis-

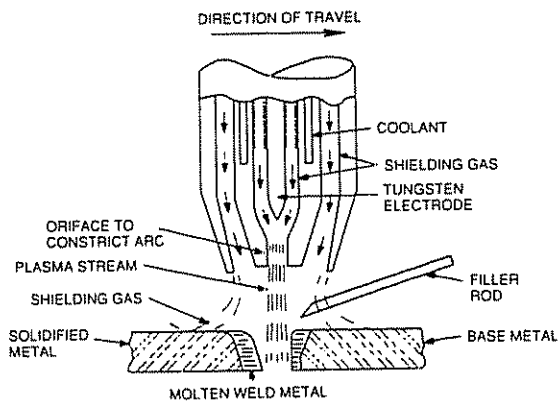


Fig. 4-42. Plasma metal inert gas welding.

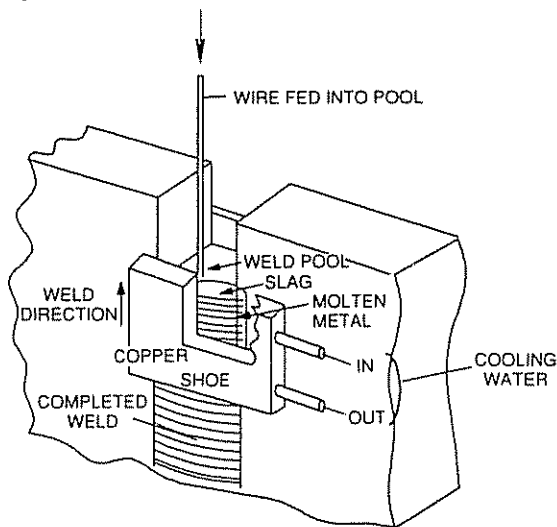


Fig. 4-43. Electroslag welding

tance welding. Often, a cooled backing plate is used behind the workpiece to contain the molten pool. Another process, electrogas welding (see Figure 4-44), employs a similar setup but uses a flux-coated electrode and CO_2 gas shielding. Both of these processes are very efficient for automatically making vertical butt welds and are highly advantageous for thicker plate. These techniques can be expected to receive considerably wider application in shipbuilding.

Thermit welding is a process that uses superheated liquid metal to melt the workpiece and provide filler metal. The liquid metal results from a chemical reaction between a

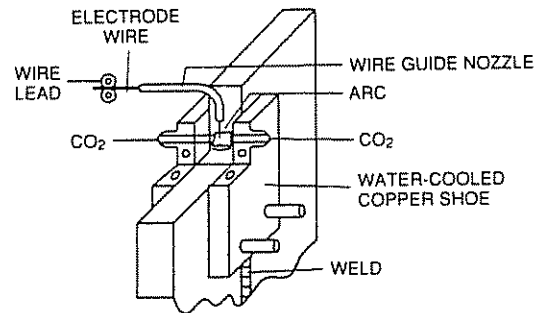


Fig. 4-44. Electrogas welding.

metal oxide and aluminum. The liquid metal is poured into the cavity to be welded and the cavity is surrounded by a sand mold. Thermit welding is somewhat similar to casting and is primarily used to repair castings or forgings or to weld large structural sections such as a stern frame.

Laser welding is a new technology which uses a laser beam to melt and join the workpiece. Although the feasibility of laser welding has been proven, cost has prevented its commercial application to date. The potential for efficient, high-quality welding may make laser welding an important technique for shipbuilders in the future.

Another relatively new welding technique is called electron beam welding. The weld is made by firing a stream of electrons through an orifice to the workpiece, which is surrounded by an inert gas. Electron beam welding does not depend on thermal conductivity of the material to melt the metal. Consequently, both lower energy requirements and reduced metallurgical effects on the steel are significant benefits of this technique. As with laser welding, high cost is a major problem.

2.6. Soldering and Brazing

Soldering and brazing are techniques for mechanically bonding two metal surfaces without fusing the parent metal. A liquid is made to flow into and fill the space between the two surfaces and then solidify. The filler material must have a lower melting temperature than

the parent metal for it to flow without melting the parent metal. If the melt temperature of the filler metal is above 450°C , the process is called brazing. In soldering and brazing, the liquid flows into and fills the gap by capillary action. In both processes, flux is used to create the proper protective atmosphere for the joint.

Soldering is commonly done using a soldering iron, by flame heating, resistance heating, or induction heating. Dip soldering, in which the assembly is dipped in a bath of molten solder, is also employed. Brazing methods include the use of flame heating, resistance heating, and induction heating. Brazing may also be done by dipping in a bath.

Soldered and brazed joints do not typically have strength properties that are equivalent to welded joints. They are therefore primarily used as sealing and bonding agents, with the strength of the joint generated by mechanical interlocking. Consequently, brazing and soldering find primary shipbuilding application in small diameter pipe joints, sheet metal fabrication, and in some joinery work.

2.7 Distortion Removal

Even where the best-known techniques are employed to avoid distortion caused by heat processes, enough distortion often remains to adversely affect the efficiency of subsequent assembly work. Thus, for productivity reasons, line heating can be applied for fairing after gas cutting parts, subassembly, and block assembly. In each such manufacturing level, line heating for removing distortion is a regular work process equivalent to marking, cutting, fitting, or welding. Line heating is also applied for fairing after erection, but is required in significantly lesser amounts than when not applied throughout the earlier manufacturing levels.

Compared to conventional methods for fairing, properly applied line heating produces more accurate finishes and has less

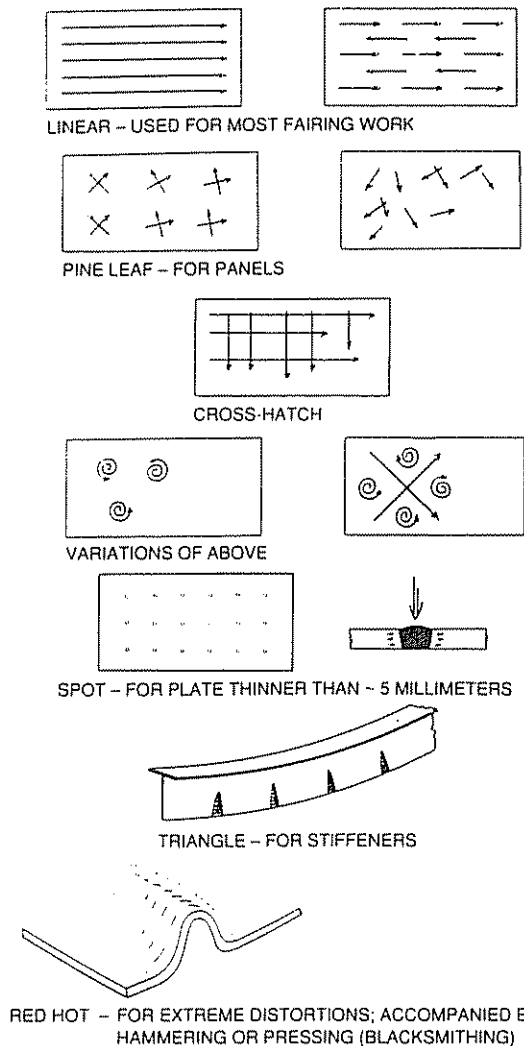


Fig. 4-45 Classification of fairing methods

impact on the strength characteristics of materials. However, some shrinkage is inherent in line heating, and the process cannot be applied to all fairing problems. Other fairing methods, such as spot heating, triangle heating, red-hot heating, and mechanical bending may be employed. Basic classifications of the various fairing methods are shown in Figure 4-45.

Surrounding members often have an impact on the effectiveness of fairing methods for a distorted region. Prestressing with jigs, jacks, gravity, or other mechanical means,

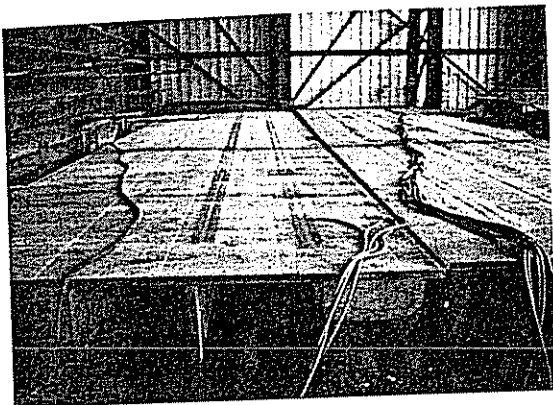


Fig 4-46(a)

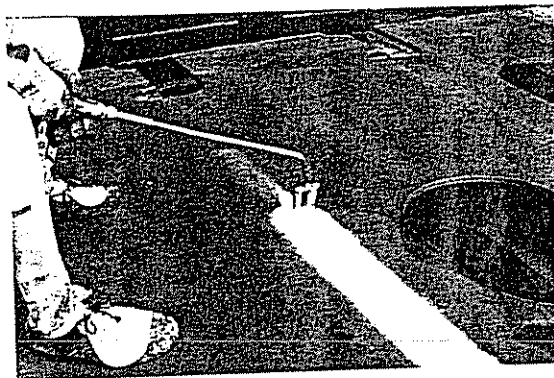


Fig. 4-46(b)

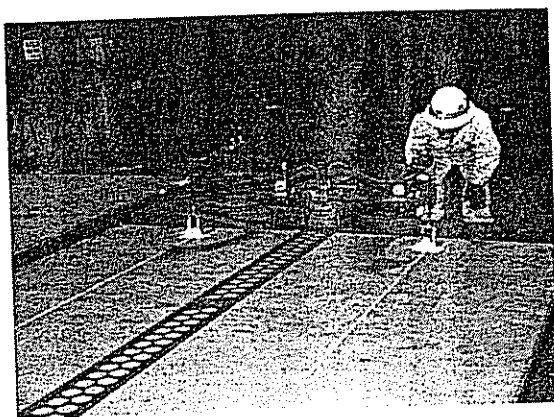


Fig 4-46(c)

Fig 4-46. Distortion removal following stiffener welding (a) On heavy plate (courtesy Avondale Shipyard) (b) Using a manual double torch tip (c) Using a semiautomatic torch tip.

followed by line, triangle, or spot heating is often effective. Extreme indentations or creases usually require red-hot heating and pressing or hammering (blacksmithing).

As for forming curved plates, water cooling is effective for most fairing work but is not

permitted for many high-strength steels. Air cooling is effective for the latter and, regardless of materials, also for fairing the surfaces of subassemblies, including blocks. Applications of some distortion-removal techniques are illustrated in Figures 4-46 and 4-47.

3. Outfit Processes

Outfit includes all nonstructural parts of a ship. Among these items are:

- main propulsion systems and auxiliary machinery
- pumps and piping systems
- heating, ventilation, and air-conditioning machinery and systems (HVAC)
- electrical systems

- accommodations and hotel services
- deck and cargo space equipment
- weapons and combat systems for naval vessels

Design of these systems is adequately described in the technical literature, in general in mechanical engineering and electrical engineering texts, and for shipboard application

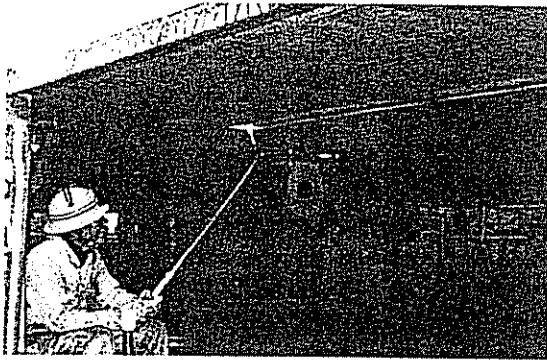


Fig. 4-47(a)

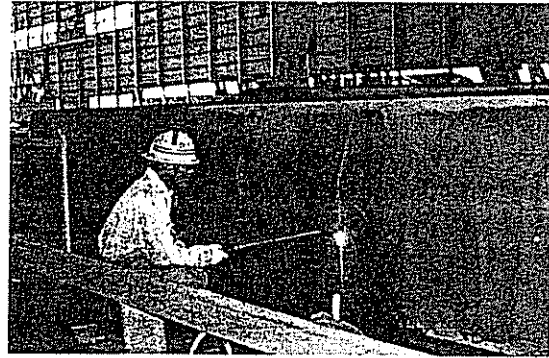


Fig. 4-47(b)

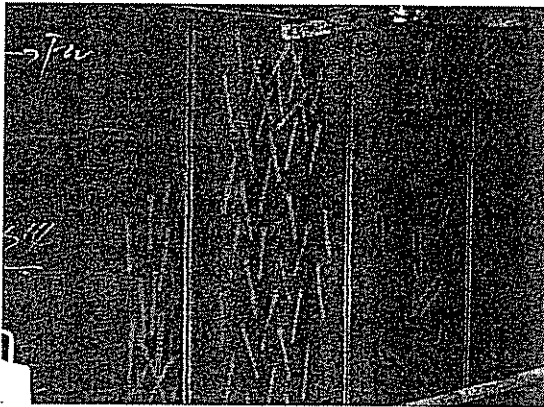


Fig. 4-47(c)

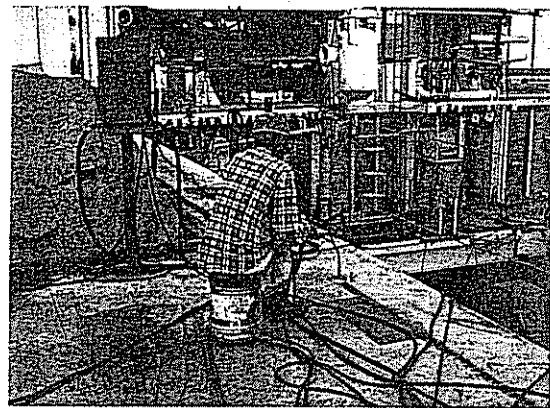


Fig. 4-47(d)

Fig. 4-47. Distortion removal. (a) At a block butt joint. (b) At a hatch coaming. (c) At a bulkhead, using a pine leaf pattern. (d) At a deck, using a water ring surrounding a torch (courtesy Avondale Shipyard)

in *Marine Engineering*. [12] This section will highlight shipyard manufacturing and construction processes for these systems. Organization of and responsibility for outfit work may vary from shipyard to shipyard, subject to local traditions, union jurisdictions, subcontractor arrangements, and other considerations. Some overlap between the categories discussed below is likely to occur. As for steel processes, outfit processes are subject to regulatory body, classification society, and/or U.S. Navy requirements.

3.1. Machinery

Almost without exception, standard shipyard practice is for main propulsion and auxiliary machinery to be purchased directly from out-

side vendors or supplied by owners as owner-furnished equipment. Consequently, shipyard responsibility is primarily the installation of equipment, including provision for adequate foundations, connection of required auxiliaries (piping and electrical), shaft connection and alignment, and system testing. The actual manufacturing processes are external to the normal shipbuilding functions.

Machinery installation in the shipyard employs basic welding and bolting combined with the requirements for support (foundations) and machinery operating specifications (alignment, vibration absorption, etc.). Shock mounting of much or all of the machinery is common in naval ship construction. Depending upon the type of ship being built

machinery installation is often confined to a few specific internal spaces. This includes the engine room, auxiliary machinery spaces, and cargo-handling machinery spaces.

An important part of the installation of main propulsion machinery is the installation and alignment of the shaft. Shaft alignment is accomplished in many ways, depending on the individual practices of a shipyard. The key is to obtain an alignment that satisfactorily distributes the load of the shaft on the bearings and allows for proper main reduction gear tooth contact. Commonly, shaft alignment is an iterative process. It begins by projecting a straight line forward through the stern tube bearing to establish the height of support points, including bearings, the reduction gear, and the main engine. Based on these data, plus the results of computations concerning load distribution and shaft stiffness, the heights of the components along the line of the shaft can be adjusted using shims and chocks. These may be readjusted following test and trials.

The installation of machinery is accomplished on-unit, on-block, and on-board during construction, and is commonly called outside machinist work. Shaft alignment is also a part of the outside machinists' work.

Some shipyards have machine shops with typical equipment, including drill presses, lathes, grinders, and milling machines (see Figure 4-48). Although they may be used for some equipment manufacturing, primary uses of this inside machinist capability are for repair of equipment removed from existing ships, and maintenance and repair of shipyard equipment. Machine shop operations within a shipyard are not sufficiently different from independent machine shop operations to warrant further discussion here.

3.2. Piping

The manufacture and assembly of piping systems represents one of the largest outfit tasks in shipbuilding. Pipe pieces are manu-

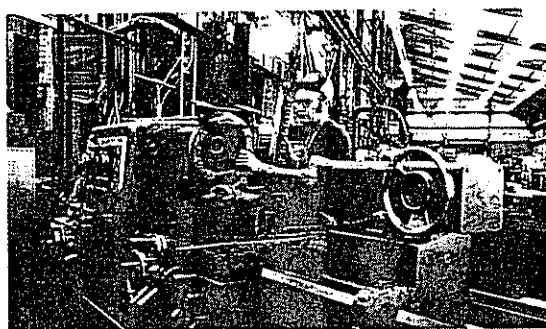


Fig. 4-48 Shipyard machine shop (courtesy Ingalls Shipbuilding)

factured in pipe shops in most shipyards and then delivered to the assembly site, whether assembly is on-outfit units, on-block, or on-board the ship. The integration of pipe piece assembly work into the complete shipbuilding system is discussed in detail in Chapters III and VII. The design of various piping systems (fuel oil, bilge and ballast, fire main, etc.) is discussed in detail in *Marine Engineering*. [12] This section will outline the specific pipe piece manufacturing processes.

Piping assembly is accomplished either by welding (including brazing and soldering) or by bolting. The specific processes involved in pipe piece manufacturing include cutting, edge preparation for welding, hole and contour cutting, flange fitting and welding, and bending. Additionally, functions related to other aspects of shipbuilding that also apply to pipe piece manufacture include surface preparation and coating, testing, including X-ray or other weld-testing procedures, and material handling.

In general, pipe piece manufacturing processes and equipment are dependent on the pipe size and material. Shipboard piping materials are predominantly steel, but also include nonferrous metals such as copper and alloys, and plastics (PVC). Generally, pipe over 2 inches (50 mm) in diameter is commonly steel, and manufacturing processes can be subdivided between pipe over 2 inches (50 mm) in diameter and pipe less than 2

inches (50 mm) in diameter. Depending on the particular shipyard and the quantity and variety of pipe pieces manufactured, further subdivision may be warranted.

Pipe cutting processes can be mechanical or thermal. Mechanical cutting is performed using stationary band saws or rotating machine tools (see Figure 4-49). Semiautomated stationary abrasive cutoff saws may be used in some pipe shops. Portable or stationary propane torch or plasma arc cutting are common thermal processes (Figure 4-50). Thermal processes are generally used to make contour cuts or hole cuts for fabricated saddles or branches. Often, numerically controlled plasma arc machines are used for complex cutting and edge preparation.

End preparation, when not performed as part of a thermal cutting process, is done using portable grinders, either manually or semiautomatically, on tracked guides. Boring mills or pipe lathes are also used for mechanical end preparation. The pipe lathe is preferred, since it can easily be adjusted to handle straight pipe of almost any material, length, and diameter.

Pipe piece welding, including welding of flanges and branches or tees, is usually done using submerged arc or gas metal arc (GMA) processes. Occasionally, gas tungsten arc (GTA) may be used for a root pass followed by GMA, especially for larger-diameter pipe. Automat-

ic flange fitting and welding machines are becoming more common in shipyard pipe shops.

Certain operations require that material in a localized area of pipe be upset or formed into a prescribed shape. Such operations include the swaging of pipe ends to a larger diameter, the similar operation of forming pipe reducers from short pipe sections, and the extrusion of bosses directly on the pipe. Shipyards may swage the ends of copper-nickel pipe in order to minimize the use of pipe couplings. One such process uses handheld mandrels to swage the ends of heater coil piping; the mandrel is simply struck with a hammer to form the swage of the proper size. These same devices can be used to make pipe reducers from short pipe sections, although the more common method is to use a forming jig on a conventional lathe. The pipe-bending phase can be the most expensive phase of work in the pipe piece fabrication process. Considerable capital investment is required to set up and use even the simplest of bending equipment. This fact has forced some shipyards to fabricate all but the smallest piping with purchased elbows.

The two basic processes of bending are cold bending and hot bending. Cold and hot bending can be further subdivided into bending with or without internal support. As wall thickness and bend radius decrease relative to pipe diameter, internal support may be

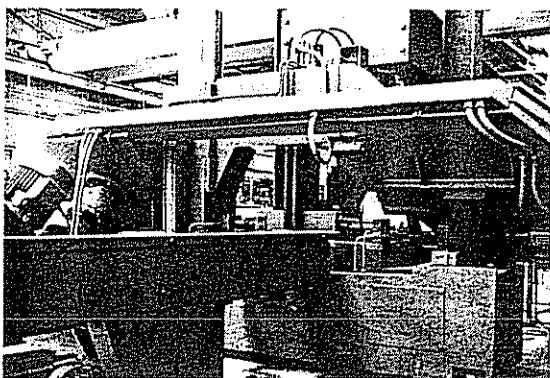


Fig. 4-49. Pipe shop band saw (courtesy Avondale Shipyard)

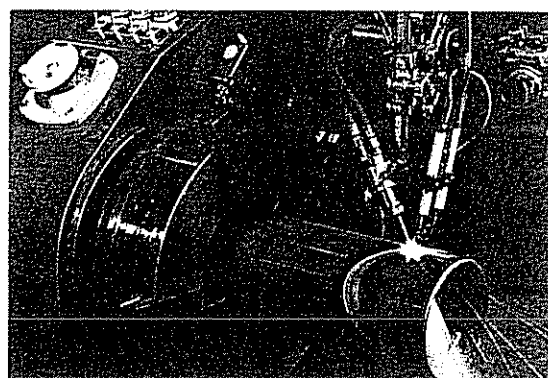


Fig. 4-50. Plasma arc pipe cutter (courtesy Avondale Shipyard).

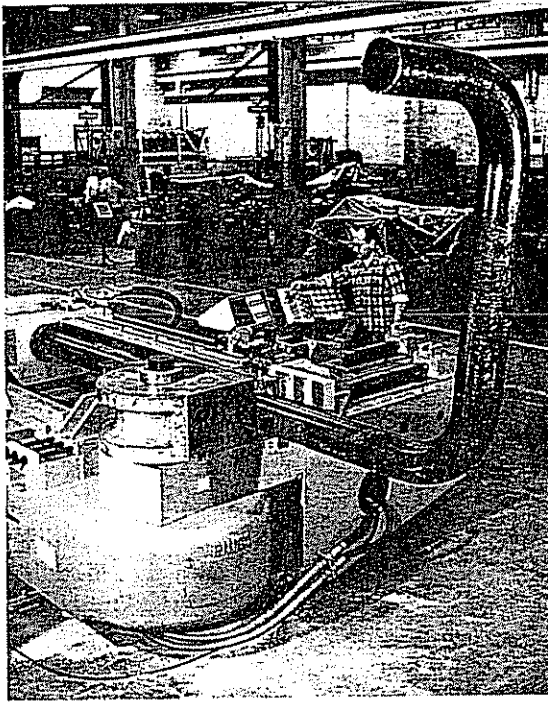


Fig 4-51 Pipe bending machine with numerical control (courtesy Teledyne Pines)

needed to retain roundness or to prevent collapse. As size, thickness, bend radius, and available equipment permit, the preferred order of use of bending processes is as follows:

- cold bending with pipe empty, using external formers
- cold bending with booster, using external formers and internal mandrels
- cold bending, using external formers and internal mandrels
- cold bending with pipe packed with sand or other filler, using external formers
- hot bending with pipe empty
- hot bending with pipe packed with sand

All bending processes normally produce some thinning of the wall at the outside arc of the bend. For any given service, a minimum wall thickness is required for each pipe size to suit the design pressure and temperature condi-

tions for service. The ordered thickness includes allowances for normal thinning due to bending; with proper use of bending methods and equipment, thinning due to bending does not cause a problem. Out-of-roundness must also be kept within established design criteria, consistent with the capabilities of the pipe shop equipment; generally, out of roundness cannot exceed a given percentage limitation for a specific material and application.

Machines for the cold bending of pipe come in a wide variety of sizes and can be manufactured to suit customer specifications (see Figure 4-51). For example, pipe-bending machines can be designed to be used with or without numerical control consoles. One of the most advanced machines is a numerically controlled booster bending machine which can bend Schedule 40 pipe of almost any material to a two-diameter-bend radius. A 1.5-diameter booster-bending machine is also available.

There is a wide range of hot bending capabilities. In general, hot bending is an expensive, inefficient, and time-consuming process and therefore is avoided if at all possible. Hot bending is most commonly used for pipe over 6 inches (150 mm) in diameter, since most shipyards do not have cold bending machines capable of handling larger sizes. Hot bending equipment requires considerable space and can adversely impact schedules due to its time-consuming nature. One practical alternative to hot bending is to fabricate with elbows. Another alternative is to subcontract this work out to facilities specifically set up to hot bend large volumes of pipe in various materials, sizes, and schedules.

Following production, pipe pieces are marked or tagged and palletized for shipment to the assembly location (see Figure 4-52).

3.3. Heating, Ventilation, Air-Conditioning (HVAC)

HVAC work processes in the shipyard almost exclusively involve the manufacture of duct-

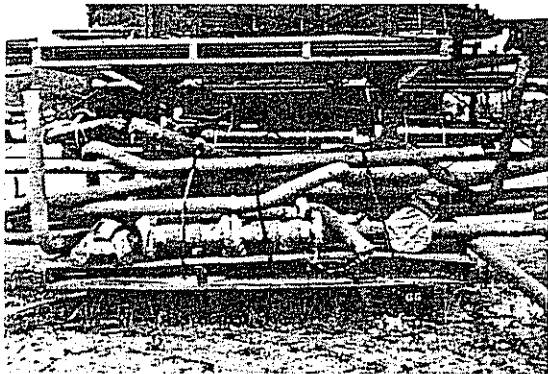


Fig 4-52 Palletized pipe pieces (courtesy Avondale Shipyard)

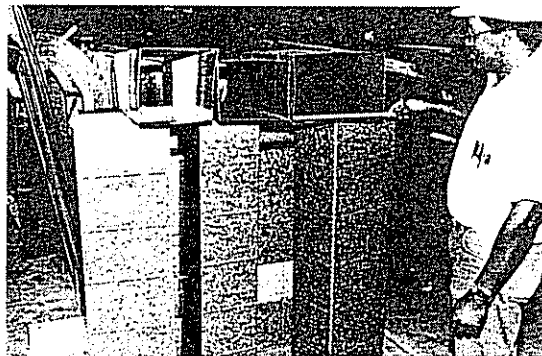


Fig. 4-53 Sheet metal duct work (courtesy Ingalls Shipbuilding)

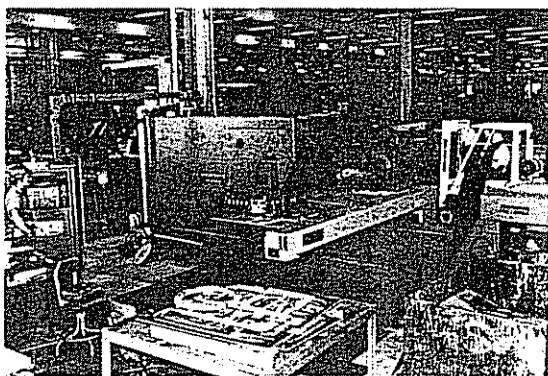


Fig 4-54 Sheet metal cutter with numerical control (courtesy Ingalls Shipbuilding)

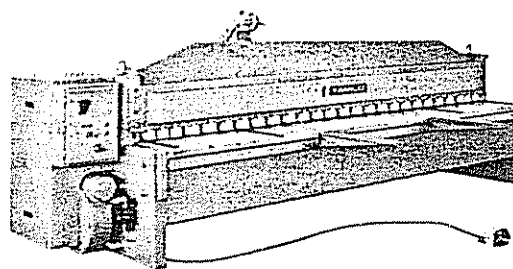


Fig 4-55 Press brake for sheet metal cutting and forming (courtesy Famco).

ing systems from sheet metal (see Figure 4-53). Other system components, such as blowers, compressors, heat exchangers, dampers, and diffusers, are generally not manufactured in the shipyard. Sheet metal ducts are made with riveted, welded, or hooked seams. Sections are joined by attaching flanges. The major processes in the sheet metal shop are therefore cutting (generally using saws, shears, or punch presses) shaping, welding, and riveting. Some shipyards use numerically controlled thermal cutting machines (see Figure 4-54). Sheet metal-shaping processes involve the use of a variety of presses. Every press contains a frame and bed, a ram or slide, a drive for the ram, a power source, and a transmission. Numerous tools and dies are also employed for accomplishing specific metal-

forming operations. Presses commonly used in a shipyard sheet metal shop are press brakes and turret presses. Press brakes can make bends in wide sheets when used with dies, or cuts (called a shearing press) when used with a long blade or knife on its ram (see Figure 4-55). Turret presses are used to pierce sheet metal to make a variety of shapes of holes (see Figure 4-56).

Installation involves welding, riveting, and bolting. Insulation is usually required and is often installed along with the duct work. Some HVAC systems may use pipe, especially for steam heating systems. In this case, the shipyard work would be performed by the pipe shop and pipefitters.

3.4 Electrical

Shipyard electrical work in new construction primarily involves running cable, splicing ca-

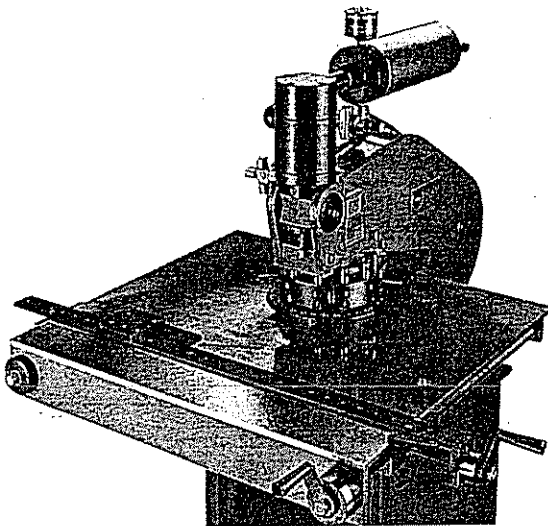


Fig. 4-56. Turret press (courtesy Thor).

ble, and making connections to equipment. Cable is generally run through cableways or supported by hangers. Additionally, the manufacture and installation of switchboards, control panels, circuit breakers, alarms, lights, and other equipment forms a part of the electrical outfit work. Since cable often must pass through watertight bulkheads, installation of cableway bulkhead penetrations is another important aspect of this work.

Trends toward increasing shipboard system complexity and automation have resulted in the need for large and complicated electrical systems. Although the work processes are comparatively straightforward, coordination of electrical installation within the shipbuilding process is very important and is discussed in detail in Chapters III and VII.

3.5. Accommodations

Accommodations are all the spaces where the crew and passengers live and work. These are primarily located in the vessel's superstructure and/or deckhouse on commercial vessels. Outfit work processes included within the general category of accommodations are called joiner work. They exclude piping, HVAC, and electrical work processes

described previously. Naturally, close coordination of all these crafts is required for productive shipbuilding. In essence, joiner work includes what was formerly woodwork on a steel ship. Wood has been almost entirely replaced by fire-resistant materials for shipboard application. These include plastics, inorganic composition materials, and sheet metal (steel, aluminum, and laminates). Joiner work therefore involves the construction and installation of nonstructural bulkheads and doors, and other means for the subdivision of living and working spaces aboard ship. Additionally, accommodations include the installation of furniture, equipment, and insulation found in these spaces on-board ship. Work processes include cutting, fitting, bolting, welding, and soldering and brazing, and are commonly manual in nature.

3.6. Deck Fittings

Deck fittings are generally fabricated from steel, comprising parts manufactured in the shipyard (such as ladders, bulwarks, railings, hawsepipes, and masts) and items purchased from vendors and installed by shipyard personnel (such as winches, windlasses, anchors and chain, and lights). Some cargo-handling equipment may also fall within this outfit category. In general, equipment requires foundations. Most deck fittings are welded in place and, consequently, the predominant work processes involved are cutting and welding of steel pieces. Some bolting may also be involved. Operational equipment requires the connection of controls (electrical) and power supplies (electrical, hydraulic piping, etc.).

3.7. Combat Systems

Combat systems aboard naval vessels consist of command and control spaces and equipment, sensors, weapons, and aviation support. Table 4-6 lists the major components of weapons systems.

Table 4-6 Weapons systems components of combatant ships

-
- *Command and Control*
 - Combat information center (CIC)
 - External communications flag
 - *Sensors*
 - Radar
 - Sonar
 - Electronic warfare
 - *Weapons*
 - Guns
 - Missile launchers
 - Torpedo launchers
 - Small arms
 - Directors
 - Handling equipment
 - *Aviation*
 - Hangars
 - Maintenance spaces
 - Stores

Combat systems consist primarily of hydraulic and electronic equipment which is generally provided by the government. Much of the installation is accomplished by shipyard personnel, frequently with the assistance of representatives from the equipment manufacturer.

A significant portion of the work involves alignment and test. In the last decade, many combatant program contracts have included provision for land-based test facilities. These may be operated by the shipbuilder or subcontractors and may or may not be located within the shipyard. Complete combat suites may be installed at the test site in the exact configuration as the eventual shipboard installation. After testing of primary and auxiliary equipment, the complete package is disassembled, shipped to the yard, and reinstalled aboard ship.

4. Material-Handling Processes

As described in the preceding two sections, shipbuilding entails a large number of separate manufacturing and construction processes. Both raw materials and equipment are delivered to the shipyard. Various operations are performed on these materials, and they are combined to produce the finished product, a ship. Inherent in this production process is the need to move material during all stages of construction, covering a wide range of sizes and weights, within shops, between shops and storage areas, and to and onto the erection site. This section will consider general categories of material-handling equipment applicable to shipyards and then consider applications of specific equipment to manufacturing and construction processes. [13]

4.1. Material-Handling Equipment

Material-handling equipment can be subdivided into four general categories: conveyors,

cranes and hoists, industrial vehicles, and containers.

4.1.1. Conveyors. Conveyors are commonly used to move materials in a fixed-path, continuous movement mode. Although common for handling bulk materials, the main shipyard applications of conveyors are for moving material as part of assembly line type production processes. These include surface preparation and coating (see Figure 4-57), steel beam lines (see Figure 4-58), and pipe shop systems (see Figure 4-59). Shipyard conveyor systems are predominantly roller type equipment and move heavy materials from work station to work station generally within a single shop. Steel plate, structural sections, and pipe may be moved on conveyor systems to perform initial surface preparation and coating prior to movement to cutting and forming work stations. Conveyors as part of

beam lines generally operate in a semiautomatic mode, providing flexibility to move plate, structural sections, and panel assemblies to desired work stations. They are nor-

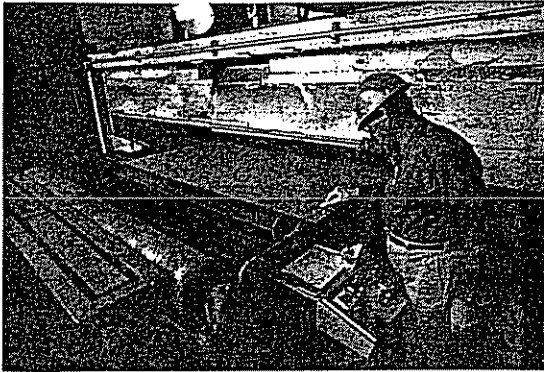


Fig. 4-57. Conveyor used at surface preparation and coating work station (courtesy Avondale Shipyard).

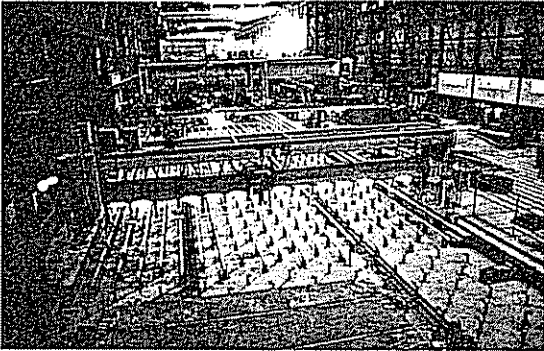


Fig. 4-58. Roller and chain conveyor in a subassembly line (courtesy Total Transportation Systems and Bath Iron Works).

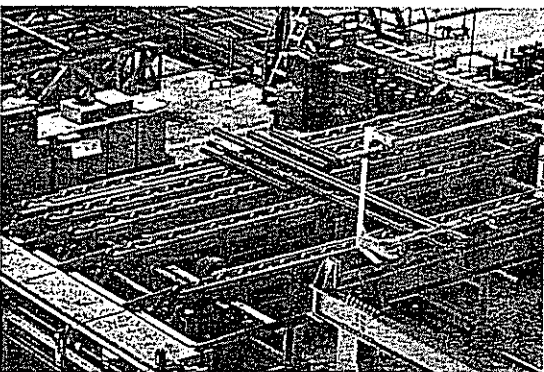


Fig. 4-59. Conveyor in a pipe shop

mally floor mounted and wide enough to handle the widest panel to be manufactured on the line. Work stations can include N/C burning and marking, plate butt welding, stiffener fitting and welding, and web fitting and welding. Conveyors provide similar advantages in semiautomated pipe shops, serving work stations such as saw cutting, plasma arc cutting, end preparation, contour cutting, hole cutting, flange welding, pipe piece assembly, bending, and weld testing. Conveyors facilitate the establishment of well-organized stations and superior material flow with much less dependence on overhead cranes. They also aid automation, including computer control, and can improve work flow. They may require additional shop floor space, although the overall improvement of work flow can compensate for this requirement.

4.1.2. Cranes Cranes are one of the most common types of material-handling equipment employed in shipyards. There are four main categories: bridge cranes, jib cranes, gantry cranes, and mobile cranes. Bridge cranes are common in shops, such as panel lines and pipe and machine shops. They may also be used in open locations. Bridge cranes require support on both sides along their full length of run. Top-running bridge cranes (see Figure 4-60) are supported by horizontal beams, which in turn are supported by ground-mounted columns. These cranes commonly have capacities of up to 300 or 400 tons, although a few 800-ton and higher-capacity top-running bridge cranes have been installed. The span for these cranes can be as much as 130 feet (40 m). Under-running bridge cranes, which are roof supported, provide easier access to large, square areas (see Figure 4-61). They generally have maximum capacities of about 20 tons and are highly dependent on the roof structure.

Bridge cranes can be cabin controlled or hand controlled (either pendant or radio controlled). Cabin-controlled bridge cranes can

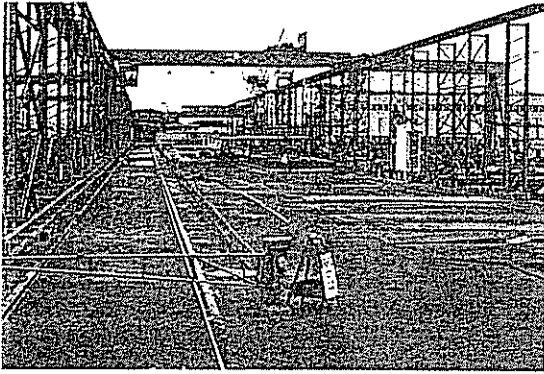


Fig 4-60 Top-running bridge crane (courtesy National Steel and Shipbuilding)

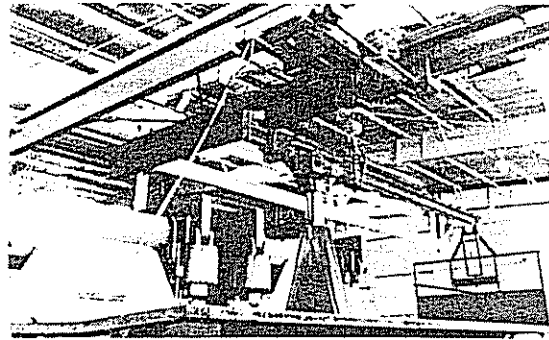


Fig 4-61 Under-running bridge crane (courtesy Acco Industries)

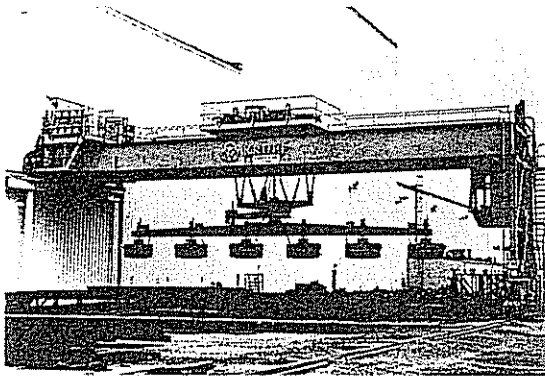


Fig 4-62 Magnetic clamp for crane steel handling (courtesy Ingalls Shipbuilding)

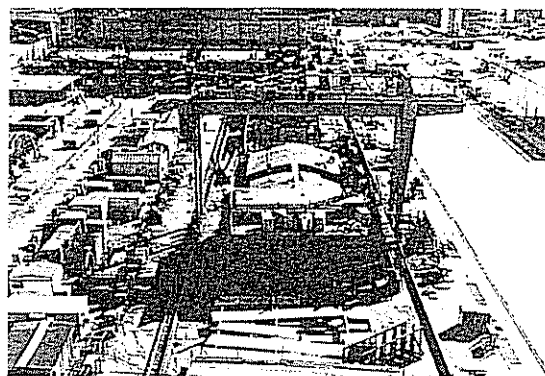


Fig 4-63 Gantry crane (courtesy Ingalls Shipbuilding)

be effectively operated in two directions at once (lifting and moving lengthways, moving lengthways and sideways, etc.). Pendant hand-controlled bridge cranes are generally restricted to moves in one direction at a time. Bridge cranes can be fitted with numerous extra lifting and moving capabilities. For example, turning capabilities can be added by mounting the lifting trolley on a turntable. Plate and structural section handling in shipyards is commonly performed by magnetic clamps or lifts (see Figure 4-62). Other special-purpose fittings are commonly available. Gantry cranes are similar to bridge cranes, except that they are self-supporting and travel in railways on the ground (see Figure 4-63). They commonly have lifting capacities and spans equivalent to top-

running bridge cranes and are normally cabin controlled.

Jib cranes, like gantry cranes, are self-supporting and run on railways. They commonly are the revolving type to permit outreach over open work areas, including erection sites and storage areas (see Figure 4-64). They normally have a counterbalance weight and a pivoting, projecting arm with one or more pick point locations. Their lifting capacities are generally less than those of top-running bridge cranes. They are cabin controlled. Common practice is to use two or more revolving jib cranes to make heavy lifts. Numerous special jigs are available for facilitating such multiple crane lifts. Hammerhead cranes are similar to jib cranes (see Figure 4-65). They are revolving, counterbal-

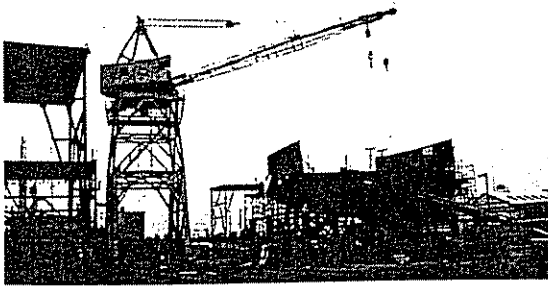


Fig 4-64 Jib crane (courtesy Tacoma Boatbuilding).

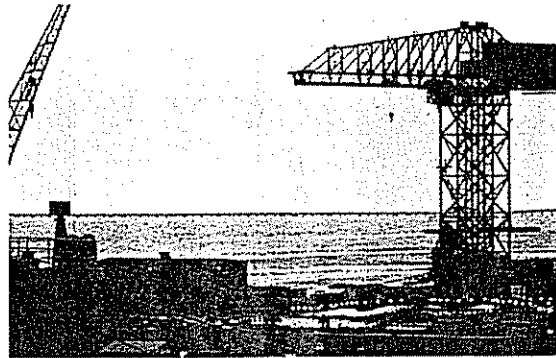


Fig 4-65 Hammerhead crane

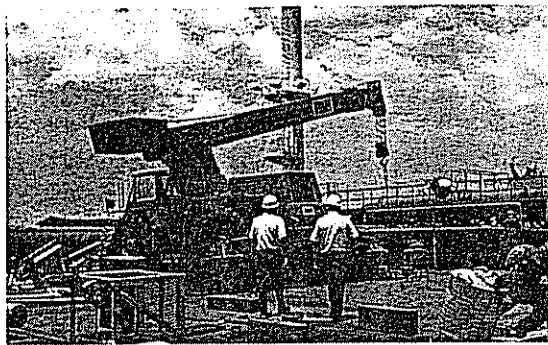


Fig 4-66 Mobile crane (courtesy National Steel and Shipbuilding).

anced, and generally cabin controlled. Unlike jib cranes, hammerhead cranes are often fixed, and therefore are most commonly used to service piers

Mobile cranes come in many types and sizes. They may be low-capacity wheeled vehicles, crawler type vehicles, or floating cranes (see Figure 4-66). Although most mobile cranes employed in shipyards are wheeled vehicles for small lifts, floating barge-mounted cranes with lifting capacities in excess of 500 tons are available in many port areas.

Various types of hand-operated hoists are available and may be used for special situations in shipyards. Chain falls, blocks and tackle, hydraulic jacks, and similar portable lifting devices are available (see Figure 4-67). These are commonly of a 15- to 25-ton lifting capacity, although somewhat larger-capacity hydraulic jacks are available.

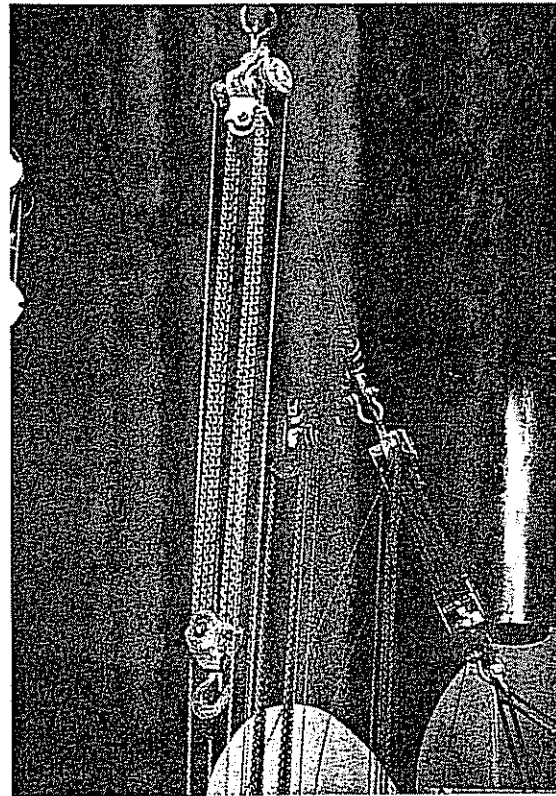


Fig 4-67 Block and tackle (courtesy Newport News Shipbuilding).

4.1.3. Industrial Vehicles Industrial vehicles play a significant material-handling role in shipyards. In general, industrial vehicles are most useful where batch sizes are small and where a wide area of coverage is required. Flatbed trucks and railcars may be used as part of materials receiving and storage sys-

tems (see Figure 4-68). These vehicles may also be used for movements within the yard. The most common wheeled industrial vehicles used in shipyards are forklift trucks. These include manual or powered drives, walker or rider operated, solid or air tired, and outrigger or counterbalanced vehicles (see Figure 4-69). There are many options that may be employed, and this versatility is one reason that forklifts are so widely used.

Also within the industrial vehicle class are the specialty, heavy-lift crawler type vehicles (see Figure 4-70). These can include treaded crawlers as well as multiple-axle wheeled vehicles. They generally have hydraulic jack lifts to permit the vehicle to move under a heavy load, jack it up, and move to another location for delivery. Although not specifically industrial vehicles, various other arrangements have been employed for heavy lifts and moves. Among these are rollers,

railway trucks, and skids of various types and designs. These may include automatic lifting and moving machinery. Some yards use a railway grid system to move assemblies and blocks to successive work stations.

4.1.4. *Containers.* The final category of material-handling equipment is containers. These are primarily boxes for holding groups of individual items, bulk containers (barrels or drums) for holding liquids and other bulk materials (such as sand or shot), and pallets. All containers provide the capability for improving material flow, material control, and work flow. Boxes are normally used for moving material within a shop or between shops, while bulk containers and pallets can be used for moves throughout the shipyard (see Fig-

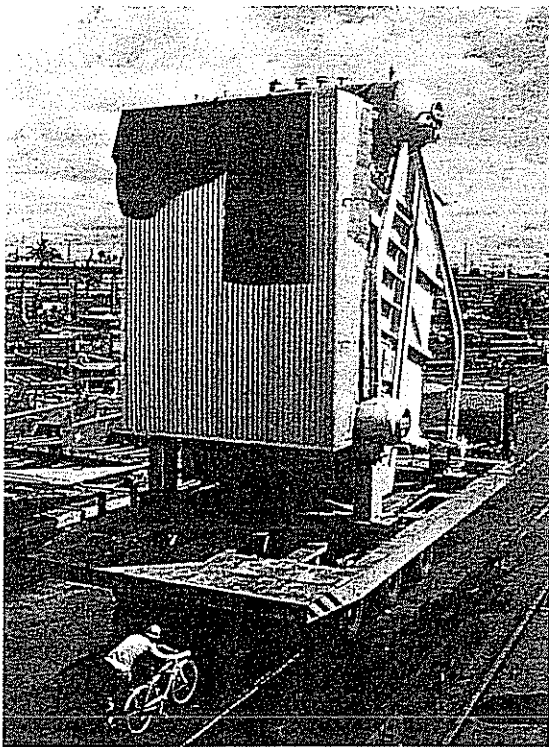


Fig. 4-68 Flatbed truck moving a boiler (courtesy National Steel and Shipbuilding)



Fig. 4-69. Forklift truck (courtesy National Steel and Shipbuilding)

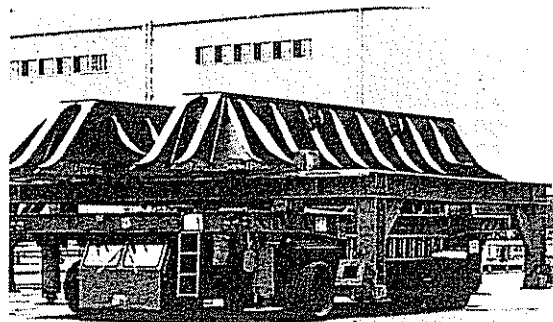


Fig. 4-70. Heavy-lift crawler vehicle.



Fig 4-71. Pallets (courtesy Tacoma Boatbuilding).

ure 4-71). Movement of containers by forklift is most common, although cranes may also be used. Most containers are restricted to relatively small load capacities, rarely in excess of one or two tons.

4.2. Material-Handling System Design

The choice or evaluation of a material-handling system is based on a number of factors. These include the material, the type of move, the method of movement, and physical restrictions on the means of material handling. Nearly all material handling in a shipyard is unit or discontinuous handling. The number of pieces of material-handling equipment can be determined from

$$n = \frac{q_d}{Z_S \cdot \eta_B \cdot \eta_{Md}} \quad \text{or} \quad n = \frac{q_M}{Q_T \cdot \eta_B \cdot \eta_{MM}}$$

where:

- n = number of pieces of equipment required
- q_d = maximum rate of material to be transported, in pieces per hour
- Z_S = maximum equipment transport rate capacity, in cycles per hour
- η_B = average operation efficiency factor
- η_{Md} = piece number efficiency factor
- q_M = maximum rate of material to be transported, in weight per hour

Q_T = maximum equipment transport load capacity, in weight

η_{MM} = load efficiency factor

Should only one piece of equipment be required, $n = 1$ and the required capacity of the single piece of equipment may be determined. The general process involves initial qualitative equipment choice based on the factors described previously, followed by evaluation of number and/or capacity required. q_d or q_M represent the material-handling needs of the system, Z_S or Q_T is the maximum equipment capacity, η_B is an operation efficiency factor related to the type of equipment, and η_{Md} or η_{MM} is an efficiency factor based on the anticipated use of the equipment. Typical values of η_B are 0.5 for a top-running bridge crane, 0.7 for a forklift, and 0.8 for an under-running bridge crane. η_{Md} and η_{MM} values indicate the percent of time the equipment is used at or near capacity as opposed to partial or light loads.

4.3. Rigging

Rigging involves the preparation of ship parts for movement by material-handling equipment. Technically this could include anything from the movement of the smallest individual pieces to the largest blocks being erected at the building site. Practically, the most important aspect of rigging is the movement of blocks, subassemblies, and outfit units (see Figure 4-72). Included is the turnover of blocks. As is discussed in Chapters III and VI, rigging is a critical part of the shipbuilding process.

Primary considerations for rigging design include shipyard material-handling capabilities, structural integrity of objects to be moved, required temporary and permanent reinforcement for blocks, subassemblies, and outfit units, pick points for lifts, including temporary and permanent lifting pads, and procedures for turnover. The need or advisability of multiple crane lifts, special mate-

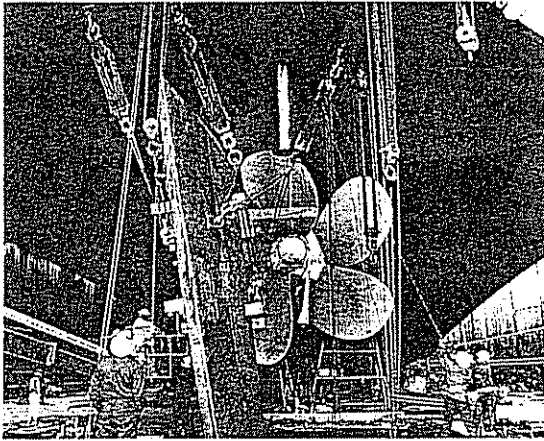


Fig 4-72 Riggers installing a rudder (courtesy Newport News Shipbuilding)

rial-handling equipment or techniques, and design and engineering requirements for rigging should all be considered as part of the rigging process.

The rigging process itself is the utilization of the material-handling equipment. It can simply be the attachment of crane hooks to lifting pads, using shackles, wire rope, or chain, or it can include attachments of multiple cranes through beams and other multiple lift jigs. Safety of personnel and avoidance of damage to completed blocks, subassemblies, and outfit units are critical factors in rigging.

4 4 Staging/Scaffolding

Temporary or moveable structures are often required to support workers, tools, and materials during the shipbuilding process (see Figure 4-73). Access to work locations must be readily available and safe. Conventional staging is constructed employing wooden planks laid across tower supports. The tower supports are portable and fabricated from bolted or clamped pipe sections, steel channel or angle sections, or other materials. Numerous combinations and designs for portable staging are employed.

Building and removing staging is of itself nonproductive work, in that it does not add

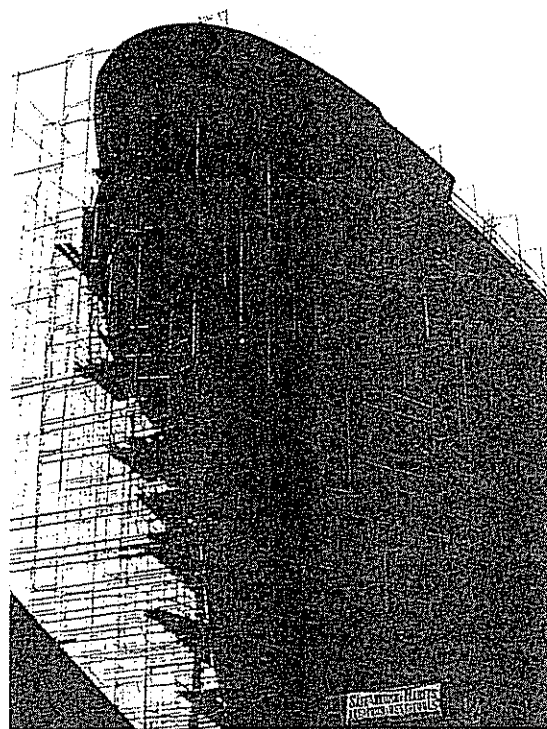


Fig 4-73. Staging (courtesy National Steel and Shipbuilding)

value to the ship. Consequently, minimization of the need for staging is an important goal. Design, engineering, production planning, and scheduling all must consider means for limiting the need for staging. Chapters III, VI, and VII discuss this further.

Some staging requirements can be mitigated by using special equipment, such as mobile hydraulic platforms, dock arms with work baskets, chain towers, and clamp-on brackets. These types of equipment can contain all necessary tools and supplies to permit easy, safe work without requiring normal staging construction. Another approach is to include permanent built-in staging in the design. The extra steel required is often less costly than erecting and dismantling temporary staging and has the additional advantage of being available for maintenance and repair of the ship during its service life. A third approach is the creation of work loca-

tions with permanent staging platforms that can be used repeatedly for building similar blocks, subassemblies, or outfit units. These

work structures can be equipped with required tools and services for the work processes to be carried out.

5. Surface Preparation and Coating

The marine environment is hard on nearly all elements of a ship. The problems of corrosion and deterioration are continual and are the result of operations in the saltwater environment, coupled with the carriage of corrosive substances (such as fuel oil and chemicals), galvanic action, biological fouling, and abrasive action.[14,15] Table 4-7 presents the factors present in the marine environment that cause corrosion and deterioration, subdivided into chemical, physical, and biological categories.

The driving force in the corrosion of metals is the consequence of their transient existence in the metallic form. In the natural state, metals occur in chemical compounds called ores. Energy is required to release the metals from these compounds. This energy, which can be considered to be stored in the metal, is released upon corrosion, which returns the metal to its natural state. Iron, for example, is commonly found in nature as hematite, an oxide of iron. Rust, the most common product of the corrosion of iron, contains the same iron oxide plus water molecules.

The energy difference between metals and their ores can be expressed in electrical terms, related to the heats of formation of the compounds that make up the ores. The relative amount of energy is reflected by the location of a metal in the electromotive series (see Table 4-8). Corrosion can take any of several forms, but most marine corrosion involves some aspect of electrochemical action. Electricity flows from one metal or area of a metal to another, conducted by water. The portion of the metal that corrodes is called an anode and the portion of the metal from which the current returns to the corroding metal is called the cathode. An electric circuit

is established, with the anode the negative pole, the cathode the positive pole, and the circuit completed by the water and a solid connection between anode and cathode. Positively charged atoms of metal leave the anode and enter the water. Their corresponding negative charges flow through the water to the cathode where they react with negatively charged ions in the electrolyte. Wasting of the metal occurs only at the anode. Commonly, the products of the cathodic reaction migrate through the solution and combine with the products of the anodic reaction to form the compounds that are the visible results of corrosion. For iron, the anodic process yields ferrous ions and electrons. The cathodic process produces hydrogen atoms and hydroxyl ions, resulting from the combination of hydrogen ions in the electrolytic solution (seawater) and the electrons released at the anode. Ferrous ions at the anode combine with hydroxyl ions from the cathode to form ferrous hydroxide, which becomes rust.

Of primary concern here are the implications of these problems for the shipbuilding process. In general, this implies the need to prepare and coat nearly all surfaces with appropriate paint or other materials. The processes involved can be generally divided into surface preparation, priming, and coating.

5.1. Surface Preparation

A ship structure could be considered a composite of a base material for strength, a coating for protection (or appearance), and an interface between the two for adhesion. To a considerable extent, it is the nature of this interface that determines the effectiveness of the composite. It is estimated that at least one-half to two-thirds of the funds expended

Table 4-7. Factors present in the marine environment that cause corrosion

Chemical	Physical	Biological
Dissolved Gases ⁽¹⁾ Oxygen Carbon dioxide	Velocity ⁽³⁾ Air bubbles Suspended silt	Biofouling ⁽⁶⁾ Hard-shell types Types without hard shells Mobile and semimobile types
Chemical Equilibrium ⁽²⁾ Salinity pH Carbonate solubility	Temperature ⁽⁴⁾	Plant Life Oxygen generation Carbon dioxide consumption
	Pressure ⁽⁵⁾	Animal Life Oxygen consumption Carbon dioxide generation

Using Iron as reference, the following trends are typical:

1. Oxygen is a major factor in promoting corrosion.
2. The tendency to form protective scale (carbonate-type) increases with higher pH.
3. Increasing velocity tends to promote corrosion.
4. Temperature increase tends to accelerate attack
5. Pressure may affect corrosion.
6. Biofouling can reduce attack, or promote local corrosion cells.

in installing a paint system for steel are allocated to surface preparation alone. Of the remainder, at least two-thirds goes for paint application, leaving only about 10 to 15 percent for the actual paint material. This allocation will vary but it does illustrate the importance of surface preparation. [16]

In the cleaning of new steel, one of the most important requirements is the removal of mill scale. This scale is formed in the hot rolling operation at the steel mill. A layer of iron oxide mill scale only a few thousands of an inch thick is formed on the surface at high temperatures. Its depth, composition, and tenacity depend on the thickness of the steel, its subsequent rate of cooling, and the steel composition. Figure 4-74 illustrates typical layer composition and cracks in each layer. During storage of steel, this scale tends to

Table 4-8. Relative location of metals in the electromotive series

Most energy required to convert ore to metal	Potassium Magnesium Beryllium Aluminum Zinc Chromium Iron Nickel Tin Copper Silver
Least energy required to convert ore to metal	Platinum Gold

flake away in an irregular manner, resulting in a dissimilar surface that includes intact mill scale, cracked and loose mill scale, rust,

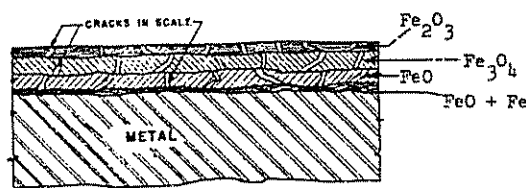


Fig 4-74 Mill scale layer composition.

moisture, dirt, oily residues, salt, sharp edges, and airborne contamination. For all anticorrosive services, thorough surface preparation is required, particularly with modern coatings, most of which will not properly adhere to an uncleaned surface.

Because paint life is dependent primarily upon surface preparation, this aspect of the painting program should receive very thorough consideration. Although all paints will fail eventually, most premature failure of paint systems is due to loss of adhesion or corrosion of the substrate. Therefore, contaminants such as chlorides, salts, sulfates, oil, and grease should be removed, along with rust and mill scale.

The choice of surface preparation methods, specifications, and equipment for a complex structure such as a ship is difficult. Some of the factors involved are ship environment, paint tolerance, profile, cost, safety, pollution, availability for maintenance, equipment availability, and surface condition.

The application of a force is required to accomplish surface preparation. The force may be mechanical, chemical, or energy radiation. Mechanical forces are applied using pressure, centrifugal action, abrasion, or direct contact. The medium for surface cleaning can be non-metallic, including sands, flint, slag, silicon carbides, or aluminum oxides, or metallic, including ferrous grit or shot, or zinc or aluminum shot. Direct-contact forces are applied using rigid abrasive wheels, flexible abrasive-coated materials, bundled wires, or cutters. Chemical surface preparation involves the

use of acids, alkalis, solvents, or reducing agents. Also, heat or steam may be used. Energy sources such as ultrasound, vibration, laser beam, or microwave may also be used.

Three mechanical techniques are predominant in shipyards. These are centrifugal (airless) blasting, nozzle blasting, and power and hand tool cleaning.

5.1.1. Centrifugal Blasting. Since their introduction in 1932, centrifugal (airless) blast cleaning machines have assumed an ever increasing percentage of the steel fabrication blast-cleaning requirements. Centrifugal blast-cleaning is ordinarily associated with the use of metallic shot or grit, with closed cabinets or blast rooms to which the work must be brought, and with the recirculation of the metallic abrasive. The abrasive is propelled to the surface, resulting in a mechanical surface preparation due to the impingement of the abrasive on the surface. The metallic abrasives are used in such a manner as not to be exposed to a corrosive environment. Their initial cost is much higher than that of expendable abrasives, but the metallic abrasives can be recirculated from 50 to 5,000 times before they disintegrate to the point where they are no longer effective. The undersized material is continually removed and replaced by a selected size of shot or grit.

Centrifugal blasting equipment can be used for steel plate and structural sections, as well as for large blocks in enclosed buildings. The original investment for such equipment is high, but the ability to recycle shot can reduce the costs associated with its use. The equipment is cumbersome, and work must be brought to it and passed through on a conveyor or rotary table so that every area can be cleaned.

An advantage of centrifugal blast cleaning over other nonautomated methods is the uniformity of the prepared surface. In order to realize this consistency in profile, the operator must add new abrasive at regular in-

tervals, at least once each eight-hour shift. Often, a depletion level of one-third is used as a rule of thumb. More exact control of the profile mix can be maintained by using screen analysis to determine the range and mix of particle sizes. The desirable procedure is to add new abrasive as the fines are removed in the dust separator and thereby maintain a reasonably consistent working mix. Prior to blasting, oil, grease, and other similar contaminants should be removed to prevent contamination of the abrasive.

Centrifugal blast cleaning of steel, followed by shop priming, prior to fabrication, has several advantages:

- defects in the steel may become evident after blasting
- layout for fabrication operations is more accurate
- burning and cutting speeds are increased
- tool life is improved
- welds are of higher quality
- the need for removal of mill scale after fabrication is eliminated, thus reducing secondary surface preparation requirements

In shipyards a priming system is often put on line with the blasting machine to coat the blasted pieces with a shop primer which protects the steel from rust during fabrication. In some shipyards, enclosed facilities have been provided for centrifugal blast cleaning of large ship sections up to grand blocks (see Figure 4-75).

Portable centrifugal blast machines, first developed in the 1960s, have recently become a commercial commodity. Even now, "airless centrifugal blasting" generally denotes a large blasting cabinet or room to which the workpiece must be transported. Environmental concerns and regulations prompted the development of portable units. Shipyards, in fact, were the first large consumers of these devices because the large flat areas of ships were conducive to using this style of equipment.

Simplifications and refinements on earlier machines have made portable centrifugal blasters economically competitive with conventional air blasting for many shipbuilding applications.

Hull bottom cleaners incorporating an up-blast design have been developed using two wheels that will clean a swath approximately 4 feet (1.2 m) wide (see Figure 4-76). Centrifugal deck cleaners come in a variety of sizes. Large, mobile, self-propelled units which clean a 4-foot (1.2-m) path were first used on aircraft carrier decks in 1975 (Figure 4-77). Commercial models of similar size, and smaller, more maneuverable, single-wheel units which clean a 20-inch (50-cm) swath, are now in routine service.

5.1.2 Nozzle Blasting. In nozzle blasting, an abrasive jet propelled by high-pressure air impinges upon the steel surface. Originally, sand was the most common abrasive but, because of health problems (silicosis), coal or

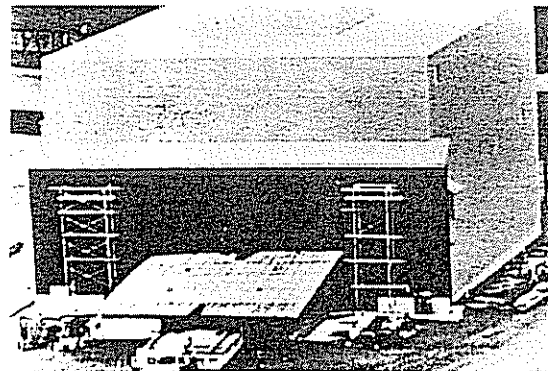


Fig. 4-75 Blast cleaning facility

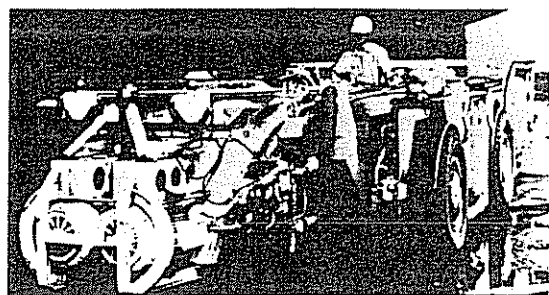


Fig. 4-76 Hull bottom cleaner.

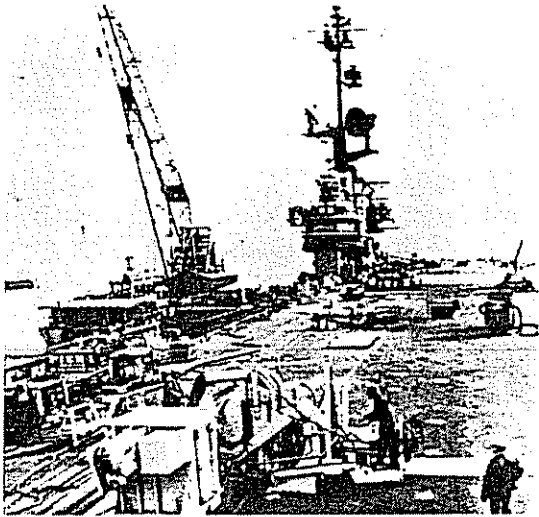


Fig 4-77 Self-propelled deck cleaning unit.

copper slag abrasive has replaced sand. Metallic abrasives are also used. Like centrifugal blasting, when metallic abrasives are used, they must be recycled to be economically feasible. A common method is to enclose the air blasting system in a blasting cabinet (for small parts) or building. Portable-nozzle blasting equipment with a vacuum return to eliminate dust and recycle the abrasive is available but, because of low blasting rates, is used only for specialized applications. The two basic types of air-blasting vacuum-recovery systems are pressure blasters and suction blasters. Figure 4-78 shows a typical portable pressure blaster. Smaller-scale units weighing only about seven pounds (three kg) have also been developed.

The pressure type units provide greater production rate, but the abrasive must be metallic grit or shot, or a recyclable nonmetallic such as copper slag, alumina, or garnet. Figure 4-79 shows a push mower style air nozzle vacuum blaster for use on ship decks.

5.1.3. Power and Hand Tool Cleaning. Hand tool cleaning consists of removing loose mill scale, rust, and paint by brushing, sanding, scraping, chipping, or a combination of these

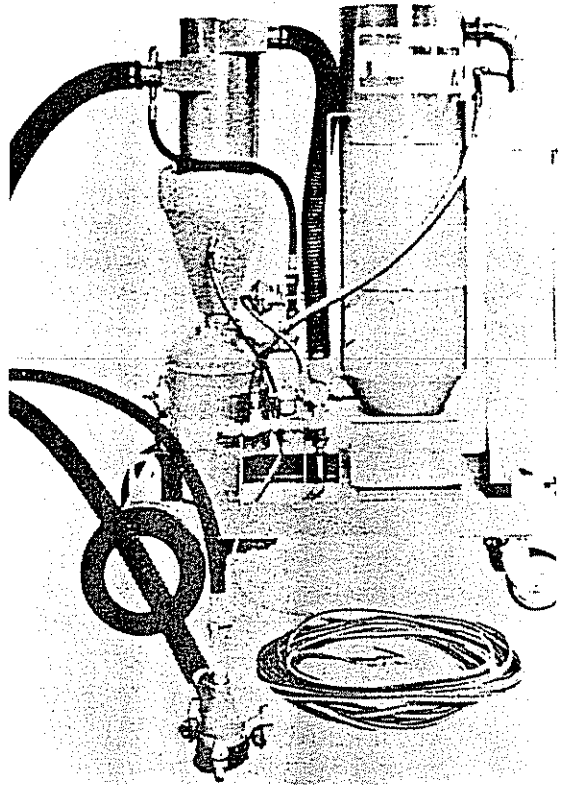


Fig 4-78 Portable pressure blaster.

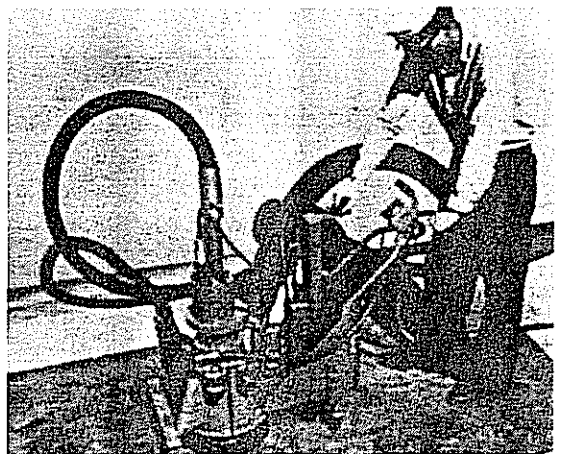


Fig 4-79. Push mower type vacuum blaster.

methods. Some of the common tools are wire brushes, scrapers, chisels, knives, chipping hammers, and, in some instances, emery or sandpaper

For power tool cleaning, the rotary wire brush or disc sander is widely used. Other tools in frequent use include impact tools and grinders. Chipping hammers are sometimes necessary when considerable rust scale or heavy paint formations must be removed. Great care must be exercised in using them, however, because of their tendency to remove sound metal and leave sharp burrs which will cause premature paint failure. Recent developments in power tool cleaning include abrasive-impregnated nylon filaments and the use of elastomer bristle supports. The needle gun has also been found effective in medium to heavy de-rusting and de-scaling.

Hand tool or power tool cleaning should be preceded by solvent cleaning to remove oil and grease and should only be expected to remove loose rust and mill scale. Care must be taken not to overbrush or burnish the surface so as to interfere with proper paint adhesion.

Pneumatic abrasive tools are the type used by most yards, although some do use electric abrasive tools. Many yards are either switching or planning to switch to air power for most of their surface preparation work. Several reasons for this move to pneumatic tools are:

- air-powered tools are light, small, and easy to handle
- they do not overheat
- the maintenance requirements are low
- there is no danger of electric shock

New centrifugal flagellating devices have only recently been developed. Tungsten carbide shot is metallurgically faced on metallic support bases which are mechanically attached to a strap. These strap assemblies are fitted into a slotted hub to form the peening wheel (see Figure 4-80). The hub can have a length from about 1 inch (25 mm) to 50 inches (13 cm) and therefore can be adapted to hand-held units or larger automated systems. The cleaning rate for scale removal is in the

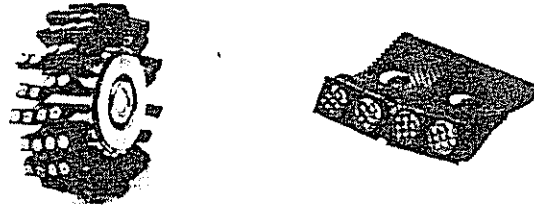


Fig 4-80 Centrifugal flagellator.

range of 2 to 3 feet (60 to 90 cm) per minute, which is about 1.5 times slower than abrasive blasting. This device is especially suited for large flat surfaces but is of limited use around such obstacles as bolts and corners. For these rough or uneven areas, a needle gun may be used satisfactorily. Needle guns, however, clean three times slower on flat areas than the rotary peening tool.

Although the peening wheel is technically a power tool, the surface resulting from this treatment very closely resembles a brush-off or commercial blast, particularly for intact mill scale. Exposure tests have shown surfaces prepared by rotary flap to be adequate for short-term exposure with several primers. The performance of coatings over roto-peened surfaces cannot adequately be compared to blast-cleaned surfaces until these exposure tests have run their course.

5.1.4. Other Surface Preparation Processes

Other techniques for surface preparation that are not commonly used in shipyards include wet blasting methods, chemical methods, and energy radiation methods. All have limitations of cost, operability, or final surface condition that have restricted their application. Wet blasting methods employ water, ice, or steam only, at high pressure, or combine water and abrasive. Wet blasting methods with and without abrasives are used to remove weed growth and similar fouling from hull exteriors during dry-docking, to prepare intact coatings for application of anti-fouling paint.

The primary chemical method used has been pickling. Although pickling (immersion in a dilute acid) can give good results, it is more expensive and less suitable for production systems for plate and structural sections than blasting and consequently is not commonly used. Pickling may still be advantageous for small parts, such as ladders, and for piping. Energy radiation methods include the use of a flame (oxyacetylene or plasma gas), lasers, ultrasonic cleaning, or microwave cleaning. To date these techniques have not been shown to be more advantageous than existing techniques, but future developments may increase their use.

5.2 Shop Priming

Following the initial surface preparation of steel plate, structural sections, and pipe to remove mill scale and to initially prepare the steel for coating, it is often common shipyard practice to apply a shop primer coat. This coat is valuable for maintaining the surface in a condition conducive to a satisfactory final product, from the point of view of both protection and appearance. Priming of plate, structural sections, and in some cases pipe is commonly an automated process performed in conjunction with and following initial surface preparation.

The primer is an extremely important part of the coating system, in terms of both final product and productivity considerations during construction. The properties that an ideal primer should possess are:

- ease of application
- optimal handling time
- quick, hard, dry time (1 to 4 minutes)
- anticorrosivity (79 months)
- good adhesion to steel substrate
- high resistance to solvents and chemicals
- weldability (should not generate pits or blowholes, nor affect strength of weld)

- reasonable flame cuttability (should not slow cutting processes)
- low toxicity
- few polluting agents (no heavy metals)
- flammability safety
- reasonable cost
- suitability for automated marking system

Any primer is likely to entail some compromise between these requirements, and a number are used. Most shop primers are zinc rich with organic or inorganic binders. Zinc silicates predominate among the inorganic zinc primers.

5.3 Coating Systems

Coating systems must be chosen and applied based on the particulars of the service of the material being coated. In general, the following classifications can be used:

- underwater (bottom)
- waterline or boot topping
- topside
- superstructure and internal spaces
- weather deck
- tanks (including piping systems)
- equipment

Many painting systems are available for each of these locations. Adequate coverage of coating systems is available in the technical literature. The coating system requires compatibility between primers and subsequent coatings. The actual coating process varies somewhat, depending on shipyard facilities, period of construction, and type and size of ship. Among the considerations are required environmental conditions, drying and curing times, application procedures, touch-up (preparation and coating), work location, and scheduling. Figure 4-81 shows a typical new construction painting process. Many shipyards have special facilities for coating work (see Figure

4-82). These enclosed structures provide adequate environmental condition control, proper lighting and ventilation, permanent staging, and ready availability of equipment. These facilities can greatly improve coating productivity and product quality.

5.4. Flame-Sprayed Coating

The use of aluminum or zinc flame-sprayed coatings has shown increasing promise in

recent years. Various gun type sprayers melt the coating material and spray it on the surface to be coated. Primary applications have been for corrosion-sensitive equipment and components for nuclear power plants, but the potential for automated permanent coating of steel plate, structural members, and pipe may make these processes considerably more attractive for more general use in the future. Flame-sprayed aluminum goes on

	Shot Blast	Cutting Welding	Block Stage	Erection, Outfitting	Launching	Outfitting, Docking Before Delivery	Outfitting	Delivery
Bottom	SP		$\xleftrightarrow{(TU)} \xleftrightarrow{AC} 2-3$	$\xleftrightarrow{(TU)} \xleftrightarrow{AC} 2-3$ $\xleftrightarrow{AF} 1$		Fresh water washing $\xleftrightarrow{(TU)} \xleftrightarrow{AC} \xleftrightarrow{AF} 1$		
Boottop	SP		$\xleftrightarrow{(TU)} \xleftrightarrow{AC} 2-3$	$\xleftrightarrow{(TU)} \xleftrightarrow{AC} 2-3$ $\xleftrightarrow{BT} 1$		Fresh water washing $\xleftrightarrow{(TU)} \xleftrightarrow{AC} \xleftrightarrow{BT} 1$		
Topside	SP		$\xleftrightarrow{(TU)} \xleftrightarrow{AC} 2-3$	$\xleftrightarrow{(TU)} \xleftrightarrow{AC} 2-3$ $\xleftrightarrow{TS} 1$		Fresh water washing $\xleftrightarrow{(TU)} \xleftrightarrow{AC} \xleftrightarrow{TS} 1$		
Superstructure	SP			$\xleftrightarrow{RP} 2$		$\xleftrightarrow{FC} 2$ $\xleftrightarrow{(RP)} 2$		
Deck	SP		$\xleftrightarrow{RP} 1$			$\xleftrightarrow{RP} 1$ $\xleftrightarrow{(RP)} 2$	$\xleftrightarrow{DK} 1$	$\xleftrightarrow{DK} 1$
Tank	SP		$\xleftrightarrow{TK} 1-3$	$\xleftrightarrow{(TU)} \xleftrightarrow{TK} 1$				
	IZ SP		$\xleftrightarrow{IZ} 1-2$	$\xleftrightarrow{(TU)} \xleftrightarrow{IZ} 1$		$\xleftrightarrow{(IZ)} 1-2$		

NOTE: SP: Shop primer AC: Anti-corrosive paint AF: Anti-fouling paint
 BT: Boottop paint TS: Topside paint FC: Finish paint
 RP: Rust preventive paint TK: Tank paint IZ: Inorganic zinc paint
 TU: Touch-up (← →): Other processes

Numbers: number of coats: e.g. $\xleftrightarrow{AF} 2-3$ means 2 or 3 coats of anti-foulant.

Fig. 4-81 New construction painting process

as an aluminum oxide, rather than pure metal. It therefore has particularly good corrosion-resistance properties and is in effect a very tough refractory. Additionally, flame-sprayed coatings can be applied in a form which gives very good nonskid properties, negating the need for frequent application of other nonskid coatings. The major problem to be solved is weldability of flame-spray-steel.

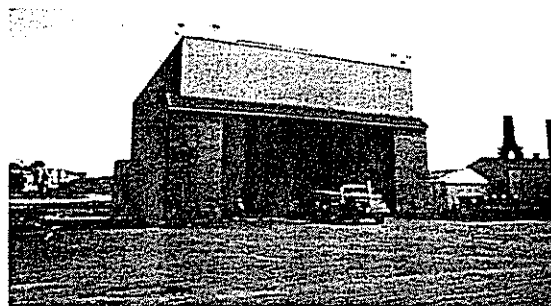


Fig. 4-82 Painting facility.

6. Quality Assurance

Quality assurance generally involves indicating that a finished product satisfactorily meets any of a set of contractually agreed-upon requirements. In shipbuilding, this can apply not only to the completed ship as a whole, but also to parts and systems within the ship. Quality assurance should not be confused with accuracy control or statistical quality control, which are discussed in Chapter VIII. Unlike accuracy control, which is an ongoing process within a shipyard, quality assurance uses after-the-fact verification.

Many quality assurance requirements are related to satisfying requirements of regulatory bodies such as the U.S. Coast Guard or the U.S. Public Health Service, or classification societies such as ABS or Lloyd's. Additional customer requirements or U.S. Navy requirements for naval ship construction are also addressed. Basically, quality assurance indicates that the completed ship actually performs as designed, both as a whole and within individual systems.

The quality assurance function is likely to be active throughout the entire shipbuilding process. The general breakdown of quality assurance requirements is similar to the breakdown of the manufacturing and construction processes. For example, classification society rules apply to minimum standards of quality for steel used in the construc-

tion. Testing of steel quality may be performed at the steel mill. Similarly, equipment testing may be performed at the manufacturer's plant prior to shipment to the shipyard. Quality assurance inspection will then continue throughout the various shipbuilding processes until the completed vessel is delivered to the owner.

6.1. Steel Process Quality Assurance

The primary testing required here is weld or casting quality testing. The techniques used include X-ray, radioisotope, ultrasonic, and magnetic particle procedures. Analysis of these tests is used to verify that cracks or imperfections are not present in welds or castings. Specific testing requirements are provided in regulatory body or classification society rules. The U.S. Navy also has established testing requirements to be applied to naval ship construction.

In addition to basic weld and casting quality testing, steel process quality assurance requirements generally include watertightness of compartments, alignment of structural components, and flatness of side and bottom shell plating and of decks and bulkheads. Following the completion of the construction of tanks and other compartments, watertightness and hydrostatic tests are conducted. These may be done using air pressure

or water, subject to applicable regulatory requirements or contractual agreements

6.2. Outfit Process Quality Assurance

Most outfit process quality assurance involves system and system component testing. In general, following completion of the construction and installation of each ship system, it is tested to assure that it satisfies design requirements. This includes machinery, electrical, piping, HVAC, and deck systems, and combat systems for naval ships. The specific testing requirements are contained in regulatory body or classification society rules or may be a part of the shipbuilding contract. Some system or subsystem testing may be conducted prior to erection on the ship. This

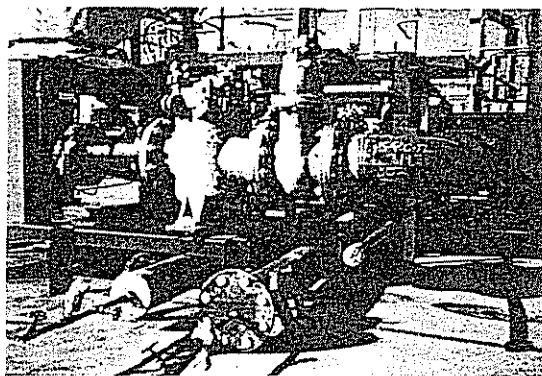


Fig 4-83. Piping unit hydrostatic test before erection

approach is particularly applicable where systems or subsystems are assembled on-unit or on-block and can therefore be tested before erection (see Figure 4-83).

7. Test and Trials

Dock trials, builder's trials, and sea trials are the normal media for conducting tests on major or shipwide systems for merchant vessels. Dock trials are used to test major outfit systems prior to completion of the ship. Builder's trials are often conducted by the shipyard to locate and solve problems before the official sea trials are held. The sea trials involve testing of the vessel and its systems underway. For naval ship construction, a similar series of trials is conducted. These are called builders' trials, acceptance trials, underway trials, and final contract trials. The specific items to be tested during sea trials are generally included in the shipbuilding contract. The following is a typical list of sea trial activities. [5]

1. Depart shipyard.
2. Ballast to trial draft
3. Adjust magnetic compasses.
4. Adjust radio direction finder
5. Standardization runs.

6. Four-hour economy run at normal power ahead.
7. One-hour water rate test.
8. One-hour boiler overload test.
9. Two-hour endurance run at maximum power ahead.
Perform turning circles.
Perform Z maneuver
Perform ahead steering test,
rudder hard over to hard over.
Crash stop to full power astern;
measure reach.
10. One-hour endurance run at full power astern.
Perform astern steering test,
rudder hard over to hard over.
Crash stop to maximum power ahead; measure reach.
11. Two-hour run at a desired lower power ahead.
12. Anchor test.
13. Deballast
14. Return to shipyard.

8. Vessel Delivery Certificates

The following is a list of the certificates generally provided to the owner upon delivery of a merchant ship.[5]

Classification Society

1. Seaworthy certificate
2. Load line certificate
3. Anchors, chains, and towlines certificates
4. Hull classification certificate
5. Loading manual, as required
6. Machinery classification certificate
7. Safety construction certificate

U. S. Coast Guard

8. Inspection certificates
9. Stability letter
10. Safety equipment certificate
11. Trim and stability book
12. Certificate of admeasurement
13. Official number certificate
14. Home port certificate
15. Panama and Suez Canals tonnage certificates

U. S. Public Health Service

16. Deratization exemption certificate
17. Certificate of sanitary construction

Federal Communications Commission

18. Safety radiotelegraph certificate
19. Radio station license

Builder of Vessel

20. Master carpenter's certificate
21. Certificate of deadweight
22. Register of cargo gear
23. List of instruction books
24. List of plans

Owner of Vessel

25. Power of attorney
26. Receipt for documents
27. Receipt for vessel

It is common practice for the shipbuilder to obtain these certificates.

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SHIPYARD LAYOUT

1. Historical Perspective

Chapter IV addressed shipbuilding manufacturing and construction processes. The linking of these processes into a production system is addressed in this chapter. The physical plant and production flow are emphasized, but with some consideration given to labor costs. Organizational aspects of the total ship production system will also be considered in Chapter VII.

Through the 1970s, shipyard layout responded primarily to advances in technology and to requirements for new types and larger sizes of ships. Changes in the layout of shipyards were, in most cases, piecemeal. Many yards are a century old and have been extended and revised with little opportunity for a complete redesign commensurate with a total systems approach.

The history of shipyard layout can be divided into three distinct periods: (1) prior to World War II, (2) World War II to 1960, and (3) from 1960 to the present. The movement from the first to the second period coincides with the changeover from riveting to welding in the late 1930s. The introduction of flow line techniques was primarily responsible for the movement from the second period to the third. Superimposed on the latter was the rapid growth in ship size after closure of the Suez Canal. The characterization of shipyards built or substantially altered during these

three periods as first-, second-, and third-generation is presented by McNeill [1]. A fourth-generation shipyard can be specified based on the development of group technology and its application to shipbuilding. These fourth-generation shipyards were developed concurrently with third-generation yards.

With this modification to the McNeill shipyard classification system, the various generations also reflect the production organization classification system presented by Marsh [2]. Figure 5-1 provides a comparison between production organizations. Shipbuilding has seen the complete range of organizations listed. Prior to the advent of welding, shipbuilding was a craft organization relying heavily on the skills of workers and little based on prior planning. Following the application of welding, most ships were built using the hull block construction method, involving the scheduling and routing of steel assemblies and blocks and the forward loading of work areas. Periods of high-volume, series ship construction, including World War I, World War II, and the supertanker building stage, saw the development of mass production shipyards. These yards had some automation, continuous flow, and relatively simple planning and scheduling. Group technology shipbuilding, as described in this text, involves establishment of fixed and well-defined workstations to pro-

TYPE	CRAFT	SEMI-PROCESS	PROCESS	PRODUCT	MASS PRODUCTION
ORGANIZATIONAL CHARACTERISTICS	PIECEMEAL PRODUCTION AND ERECTION	WORK AREAS DEFINED BUT FLEXIBLE	WORK STATIONS DEFINED AND FIXED GROUP TECHNOLOGY APPLIED	PRODUCTION FROM ALL WORK STATIONS SYNCHRONIZED WITHOUT BUFFERS	AUTOMATED CONTINUOUS FLOW
PLANNING	SIMPLE TOTAL SHIP BASIS	MORE COMPLEX SCHEDULING AND ROUTING OF UNITS AND ASSEMBLIES FORWARD LOADING OF WORK AREAS	HIGHLY COMPLEX SCHEDULING AND ROUTING OF INDIVIDUAL COMPONENTS. FORWARD LOADING OF WORK STATIONS	SIMPLER THAN PROCESS. LESS NEED FOR ROUTING INSTRUCTIONS	SIMPLE SCHEDULING ROUTING FIXED BY PLANT
EXTENT OF MECHANIZATION	INCREASING ➡				
FLEXIBILITY	DECREASING ➡				
COMPLEXITY OF PLANNING	INCREASING ➡ DECREASING ➡				
EXTENT OF STANDARDIZATION	INCREASING ➡				
TYPICAL APPLICATION IN SHIPYARD	PANEL BAY PANEL LINE CONVEYORS IN FABRICATION EXTRUSION OF HULL ASSEMBLY WORK STATIONS GENERAL MACHINERY INTENSIVE AREAS				

Fig 5-1. Production organization properties.

duce similar interim products and is a product type or group technology production organization. The categorization of shipyard layout will be presented in terms of the production organization classification shown in Figure 5-1.

1.1. Pre-World War II

This period corresponded to the job shop or craft type organization. Shipyards characteristically had limited storage and shop facilities and lift capacities in the five- to ten-ton range. Most of the ship components were assembled on or immediately adjacent to the shipway. Much of the planning was accomplished by highly skilled craftsmen as the ship was erected. Shop requirements were minimal and consisted of steel, pipe, and machine shops located near the shipways and

outfitting piers. Outfitting, including installation of power plants and auxiliary machinery, was accomplished, for the most part, after launch. Riveting was the major process employed for joining steel plates and parts. First-generation shipyards were characterized by a long, narrow layout, following along the waterway, with comparatively little depth back from the waterway (see Figure 5-2). The work was concentrated around the shipway and outfit pier.

1.2. World War II–1960

This period was characterized by adoption of prefabrication of weldments away from the shipways and development of more accurate, high-technology steel cutting and welding. The process production organization corresponds to the shipbuilding system of this

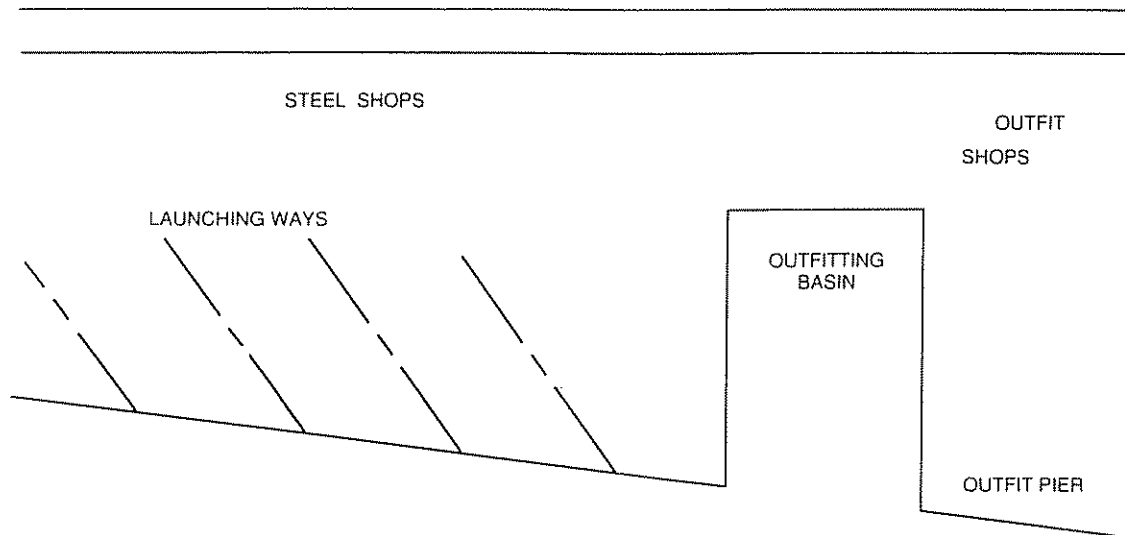


Fig. 5-2 First-generation shipyard layout.

period. Sections of the ship were built in shops and transported to the shipways where they were erected. Work areas were defined, but with some flexibility, and more complex scheduling and planning were required. Flexibility and required skill level were lower, relative to the job shop organization, and accuracy requirements were greater.

This period was ushered in by Henry Kaiser during the Second World War, at shipyards in Portland, Oregon, and Richmond, California. Other yards, responding to the high demand resulting from the war effort, adopted similar methods. However, with the dismantling of much of the U. S. shipbuilding industry after the war, due to the greatly decreased demand for ships, many of the Kaiser advances disappeared in the United States. Many of the management concepts were adapted and more fully developed by the Japanese and European shipbuilding industries, but along different lines. The differences will be discussed more fully in section 1.3. The basic ideas were combined with technological advances developed mostly in Europe, and most Western European yards developed along the lines of process organizations.

Important changes during this period included fewer shipways and more space devoted to storage and shop facilities, as more work was accomplished away from the erection site. Crane capacity was increased to accommodate the movement of larger weldments in the subassembly and erection areas. The shipways became assembly areas, rather than fabrication areas, as they were in first-generation shipyards. More accurate gas cutting and high-capacity welding methods were developed. Lofting improvements were achieved, employing 1/10th-scale optical systems. Outfitting techniques changed very little, however, and outfitting was still accomplished almost entirely after launch.

Figure 5-3 shows a typical second-generation shipyard. Compared to the first-generation layout, there is a shrinking of the length of the yard along the waterway, but an increase in depth back from the waterway. The number and size of fabrication shops increased significantly.

1.3 1960–Present

Shipbuilding in the 1960s and 1970s was particularly influenced by specialized ship types, larger ships, and a move to series pro-

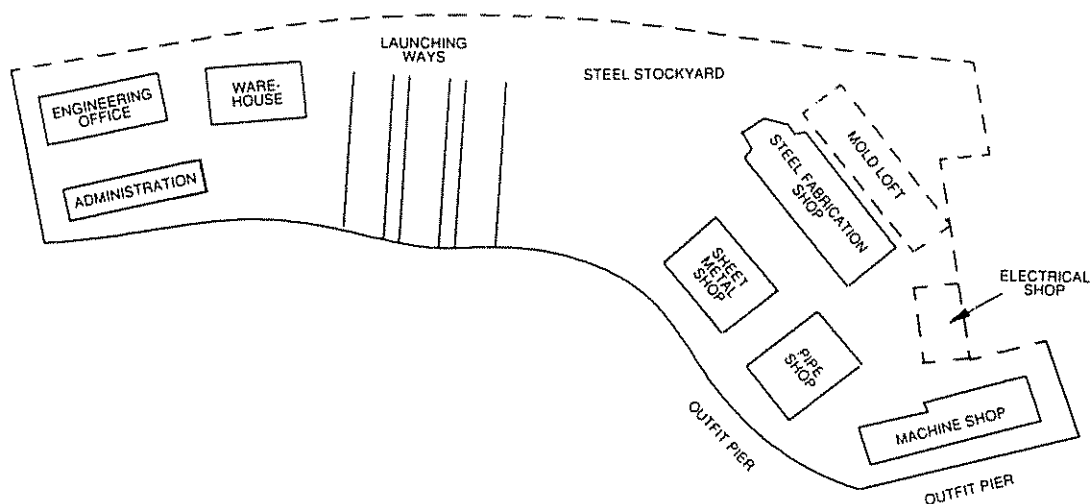


Fig. 5-3 Second-generation shipyard layout.

duction. European and some U.S. shipbuilders began to modify existing yards to accommodate this mass production type organization. Work stations were clearly defined and fixed. High technology was introduced in steel fabrication and transport. Scheduling was complex, and planning was characterized by forward loading of work stations. Flow of weldments and modules took on the appearance of an assembly line process in some yards, with the attendant loss of flexibility in product line and required quantity. For efficient production, these yards required a standardized product and high throughputs.

1.3.1. *Ship Size, Types of Ships, and Series Production.* Some yards specialized in new types of ships, such as:

- bulk carriers
- oil, bulk, ore carriers (OBO)
- roll-on/roll-off ships (RO/RO) with complex ramps, doors, hatches, and elevators, and high freeboard
- barge carriers
- cement and grain carriers equipped with specialized unloading systems

- gas carriers (LNG/LPG) which required highly advanced welding systems and insulation

Shipyards specialized in one or more of these types of merchant ships in order to attempt to gain a competitive edge in a specific shipbuilding market. Series production of a limited product line resulted in lower prices and decreased building times. Additionally, the U.S. Navy adopted a policy of contracting with a single yard for an entire class or the bulk of a class of ships. For example, all 30 of the Spruance class destroyers and 27 of the 46 FF-1052 class frigates were allocated to two yards.

A new shipyard, built to accommodate the Spruance class destroyers (see Figures 5-4 and 5-5), is an example of a high-capacity in-line process (or mass-production) yard. Workstations are fixed and assemblies are moved toward the water on a heavy-lift rail system. At each station, subassemblies are combined until, at the final station, called the integration area, the ship consists of three modules. Some outfitting (pre-outfitting) is accomplished throughout the movement of modules toward the integration area. The Spruance class ships,

for example, were launched approximately 65 percent complete. Final on-board outfitting is accomplished at a separate facility. Workstations are fixed at the outfitting piers by moving outfitting crews who specialize in particular systems and subsystems from ship to ship.

The closing of the Suez Canal in 1967 ushered in the era of the supertanker. The effect on many shipyards was a requirement for additional capacity, to permit construction of these very large ships. Only moderate changes in methodology often accompanied this expansion in capacity. Particularly in Europe, many yards attempted to get by, by launching ships in two sections, thus maintaining the modules at some maximum size. However, at some point most shipyards which competed in the supertanker market were forced to make major changes in facilities.

1.3.2. Conventional Shipyard Layout in the 1960s and 1970s. Series production and further advances in modular construction, begun in the postwar period, contributed to development of heavy-lift ground transport vehicles and cranes. Cranes capable of lifts of 200 tons were fairly common, and some yards were equipped with gantry cranes capable of lifting over 1,600 tons. Jack-up multiwheel transporters capable of moving 600 tons were also employed. Ground transporters, such as the one shown in Figure 5-6, were used in conjunction with large enclosed shot blast and painting facilities.

Modular construction created problems for conventional sloped shipways. Aligning modules was difficult, and many older shipways could not support the larger ships being built in the 1970s. In the case of supertankers and RO/RO ships, existing cranes sometimes lacked the height required. To counter these problems, graving docks were built to accommodate heavier modules and larger ships. Along with the larger building docks, many yards installed heavy-lift gantry cranes, usu-

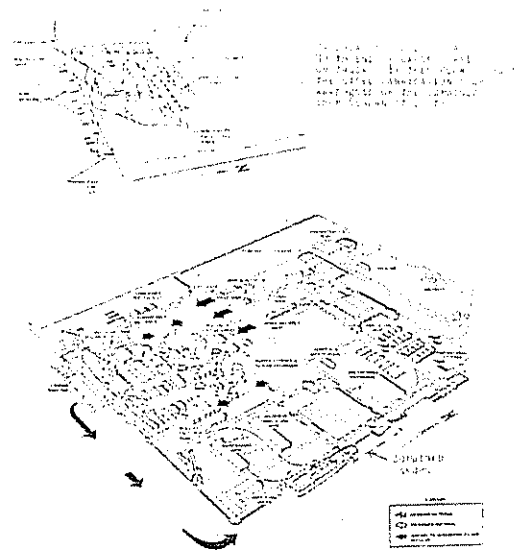


Fig. 5-4 High-capacity, in-line process shipyard (courtesy Ingalls Shipbuilding)

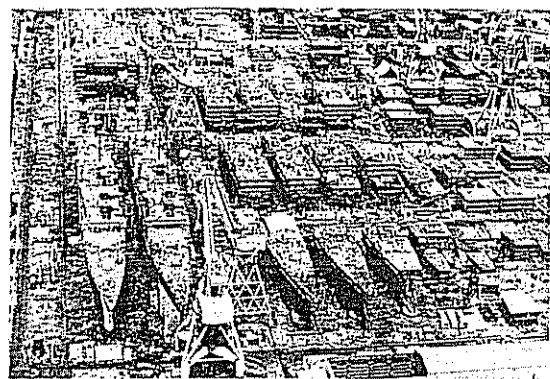


Fig. 5-5 In-line process shipyard in full production (courtesy Ingalls Shipbuilding)

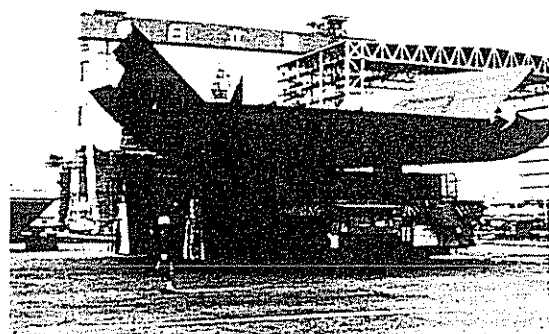


Fig. 5-6 Self-propelled transporter

ally with jib cranes positioned underneath. These jib cranes were often installed so that they could reach beyond either end of the dock.

Docks have been built in several variations, including:

- intermediate dock gates which enable flooding of part of the docks
- canal docks with openings on both ends, also incorporating intermediate gates
- multilevel docks with an upper level which can be flooded by pumping in water and a lower level which is gravity flooded

Figure 5-7 shows the layout of a typical third-generation shipyard.[1] Note the arrangement of building docks, cranes, and fabrication areas. Flow lane production techniques were introduced in third-generation shipyards. The trend to less length and more depth, begun in the transition from first- to second-generation shipyards, continued with the third-generation yards.

Modular construction and the induced requirement for large prefabricated panels and shapes also gave rise to high-capacity panel lines and the development of semiautomatic high-capacity welding systems. In the early 1960s stiffeners were usually attached to plates by hand, and webs installed piece by piece. This process was replaced by semiautomatic panel lines, where plates were welded together in long panels, and stiffeners positioned and held in place by mechanical means were welded by automatic machines. Egg-box construction was also used in some panel lines.

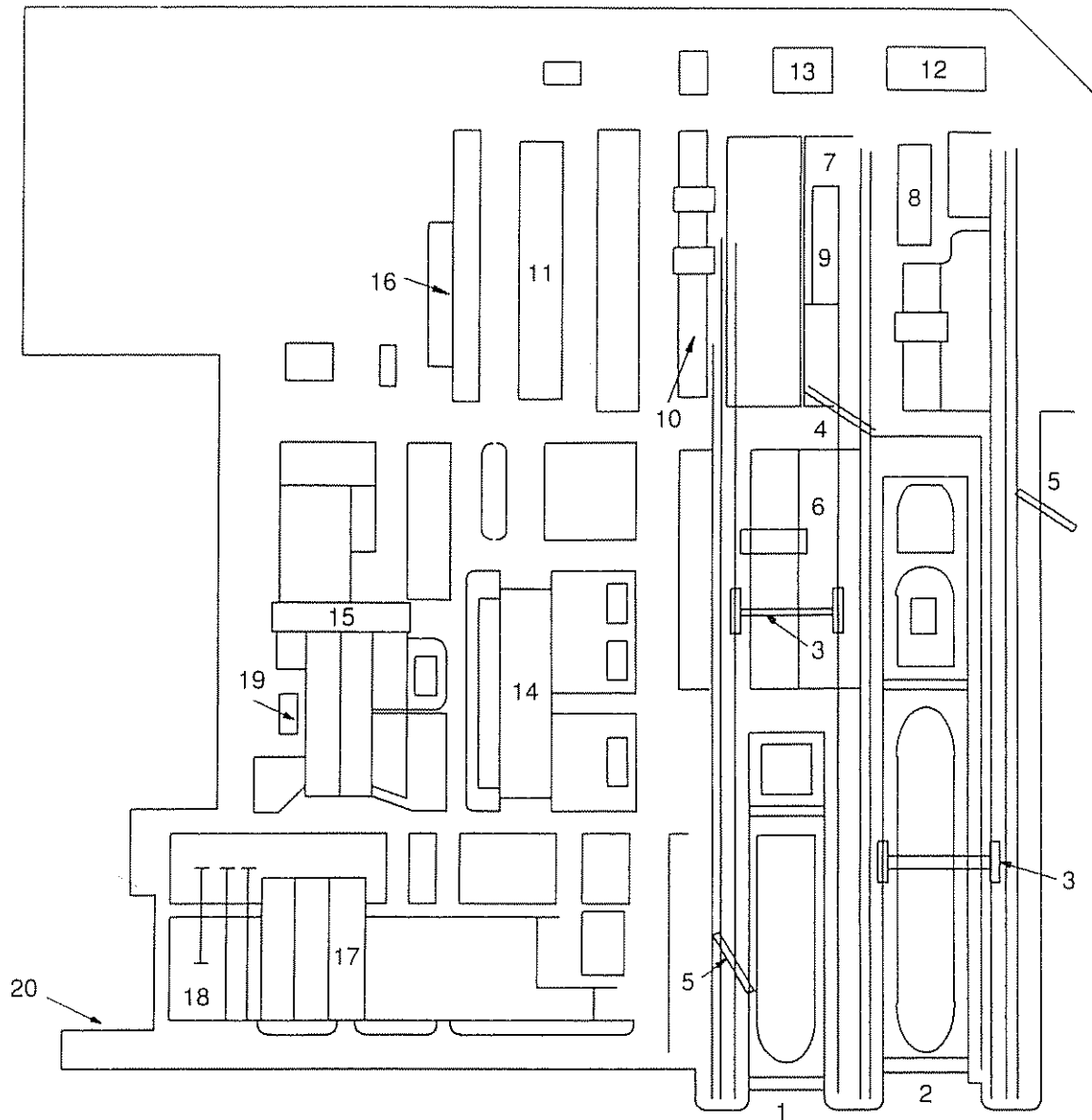
Modular construction also required more accurate and higher-speed marking and cutting systems. A major advance in the 1960s was in mold loft procedures. The traditional mold loft was a large covered loft where sections at each frame were drawn to full scale on the floor. Wood templates were then con-

structed and used to mark steel plate prior to hand burning. This system was first replaced by 1/10th-scale drawings. The 1/10th-scale drawings were used to directly guide a cutting machine head in burning right- and left-hand full-scale parts simultaneously. The cutting machine used a photosensitive cell that followed the contour of the 1/10th-scale drawings.

An alternative method was to photograph the drawings and produce a 1/100th-scale slide. A full-scale image was then projected on the plate for marking. The 1/10th-scale drawings could be used to produce offsets and then punch tapes for numerically controlled burning. However, most lofting is now accomplished using computer systems. Fairing is accomplished using computer programs in conjunction with on-screen representations. Once faired, the final lines plan is prepared and a computer data base constructed, from which numerical control instructions are produced. The numerical control instructions guide high-speed multiple plasma arc or flame burning heads.

Initial attempts at advanced outfitting (as described in Chapter III) were begun in third-generation shipyards, but without marked success. This can be attributed, in part, to a lack of understanding of the requirements for the integration of planning, scheduling, material control, accuracy control, and production control. Large modules were often constructed like small ships, using conventional methods. The modules were still outfitted to a great extent after being closed up. The final module was then heavier and created additional erection problems, without the benefit of easy access and downhand outfitting.

An example of a complication induced by large modules is the additional requirements for staging for working on these modules. Some very complex solutions to this problem were introduced by shipbuilders in Europe, Japan, and the United States. For ship prod-



- | | |
|---------------------------|------------------------------|
| 1 BUILDING DOCK | 11 BLOCK BUFFER AREA |
| 2 BUILDING DOCK | 12 OUTFITTING SERVICE CENTER |
| 3 700T GANTRY CRANE | 13 PIPE SHOP |
| 4 50T JIB CRANE | 14 FORE/AFT ASSEMBLY SHOP |
| 5 15T JIB CRANE | 15 PANEL ASSEMBLY SHOP |
| 6 ASSEMBLY AREA | 16 BLOCK PAINTING SHOP |
| 7 ASSEMBLY AREA | 17 SUBASSEMBLY SHOP |
| 8 S-STRUCTURE/ENGINE ROOM | 18 STEEL STOCKYARD |
| PRE-OUTFITTING SHOP | 19 HULL PARTS SHOP |
| 9 UNIT ASSEMBLY SHOP | 20 STEEL UNLOADING PIER |
| 10 PRE-OUTFITTING SHOP | |

Fig 5-7 Third-generation shipyard layout

uct lines that were stable, facility solutions were effective. Large jigs, capable of handling large modules of approximately the same size and shape, were developed and employed. High-cost, highly specialized capital equipment, like these specialized jigs, are characteristic of many third-generation shipyards of this period.

1.3.3. Product-Oriented Shipyard Layout. Third-generation shipyards attained a high degree of mechanization at the cost of inflexibility in product size and throughput. When the demand for ships, particularly supertankers and bulk carriers, collapsed in the mid-1970s, many shipyards went into receivership or were nationalized.

Those shipyards which did not follow the trend toward heavier lift capacity and larger modules, but improved their management by using the technology currently available, fared better. These are the fourth-generation shipyards, which incorporate the principles of group technology and are characterized by greater flexibility in planning and throughput requirements. Production is synchronized to minimize buffer storage and transport re-

quirements. Block size is optimized to accommodate zone outfitting and facilitate erection in order to maintain balanced work flow. Whereas the process type yard requires series production and massive throughputs for efficiency, the product-oriented yards realize the benefits of mass production for small numbers of similar ships and have the management flexibility to effectively build a wide variety of ship types and sizes.

Figure 5-8 is an example of a fourth-generation shipyard. [3] The two building docks (No. 1 and No. 3) are about 1,000 feet (300 m) long and 200 feet (60 m) wide. Both docks are served by two 200-ton and two 80-ton capacity jib cranes and can accommodate ships of about 180,000 dwt. At its peak the yard produced 12,000 metric tons per month with an employee complement of 4,000. An additional approximately 3,500 subcontractor personnel are dedicated to production for this one shipyard. The product line includes bulk carriers, product carriers, tankers, and containerships. The principles of the fourth-generation, product-oriented shipyard layout will be discussed in detail in the remainder of this chapter.

2. Shipyard Facilities and Siting

With the exception of the Ingalls West Bank Facility, there have been no completely new major shipyards built in the United States since the Second World War. Some major redesigns have been accomplished and more are likely. Several shipyards have begun long-range redesigns based on the application of the principles of group technology. When complete, some of these yards will be laid out essentially as new shipyards.

Regardless of whether a proposed shipyard is to be built from scratch or as a modification to an existing yard, certain factors should be considered. A thorough analysis of potential markets, market shares, vendor/subcontractor markets, labor markets, envi-

ronmental requirements, energy costs, and the availability and costs of land must be conducted. This analysis should also consider geographic/urban factors, such as:

- proximity to open sea and protection from the sea
- highway, rail, and water transportation
- availability of air transportation
- proximity of technical schools and universities

Perhaps the most important internal aspect of shipyard layout is to analyze the yard as a total system. Once a target shipyard capacity has been selected, based on the preliminary

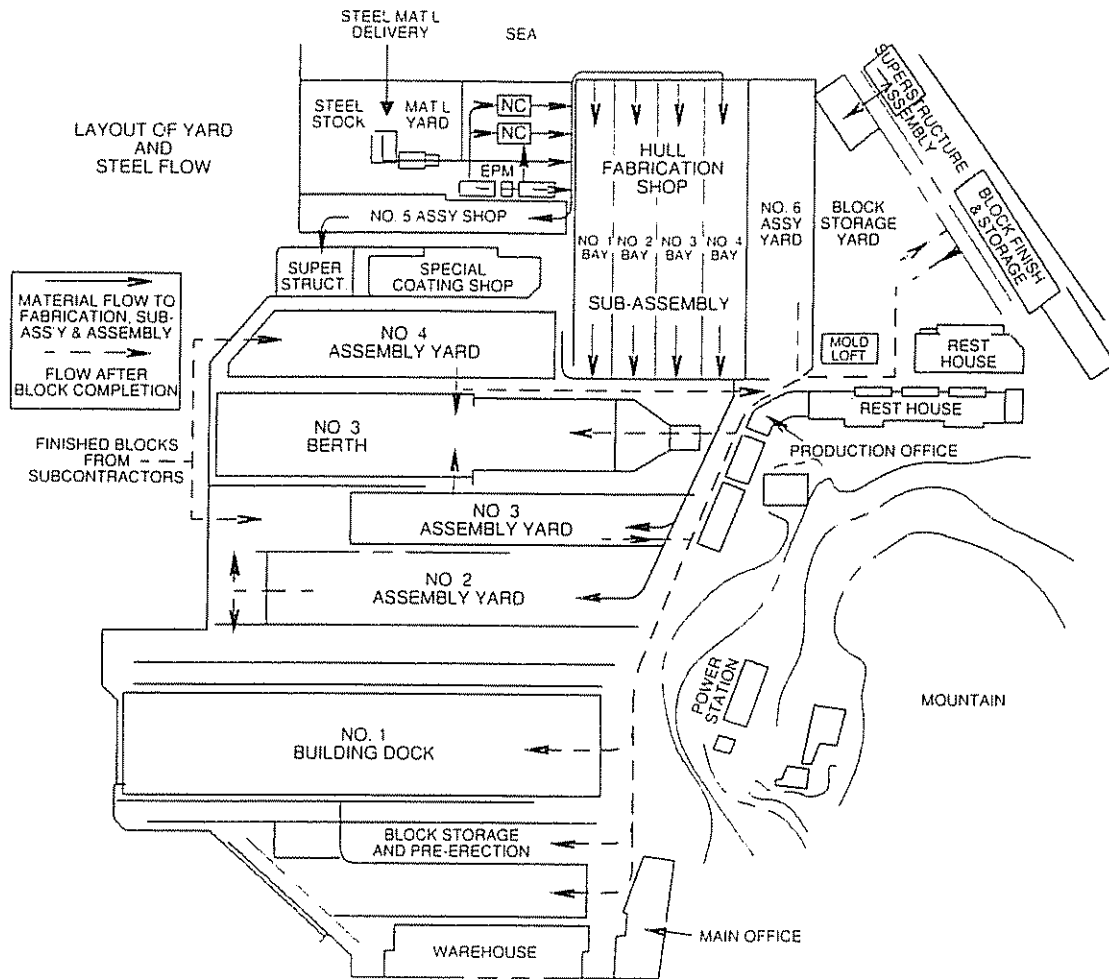


Fig 5-8 Fourth-generation shipyard layout.

market analyses, each of the yard facilities must be sized accordingly. Just as a major goal of PWBS is to balance the process flow lanes, each facility in the yard should contribute to a balanced flow of material and interim products. Goals of facility layout which must be considered are:

- optimizing material and work-in-process inventory, which implies minimizing inventory subject to some acceptable risk that a part or component will not be available when needed
- minimizing buffer storage consistent with a uniform flow throughout the yard

- minimizing the number of lifts and reducing the distance material and interim products must be transported

The following discussion of facilities layout assumes group technology ship production will be adopted. Therefore, examples of product-oriented shipyards will be used throughout to demonstrate certain principles. Figure 5-8 is an example of an established product-oriented shipyard. This yard has a new construction and repair facility. It is located adjacent to a boiler works and diesel engine/foundry works. Repair and new construction are operated as separate departments. Both the new construction and ship repair depart-

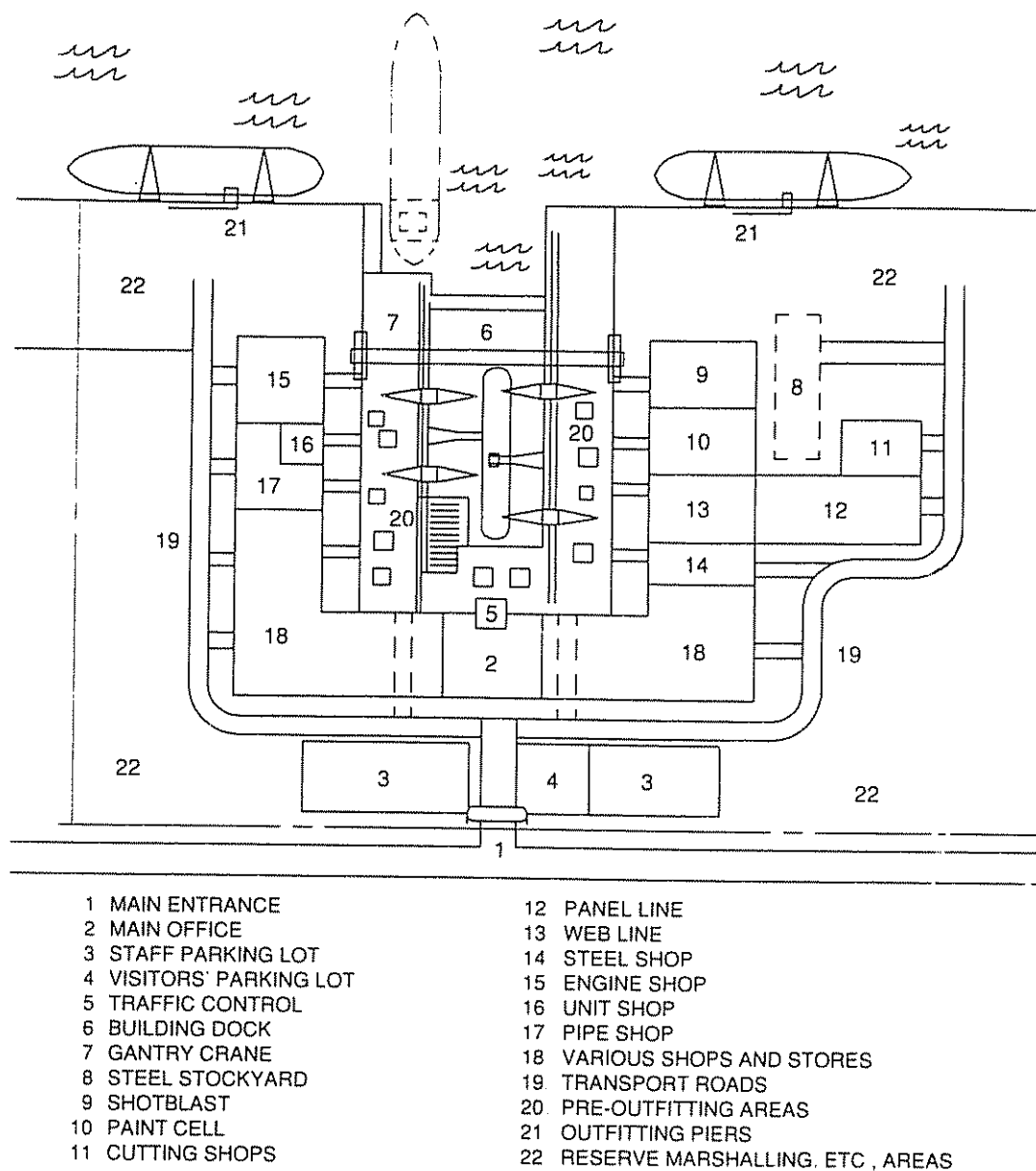


Fig 5-9. Proposed fourth-generation newbuilding yard layout

ments, along with the boiler works, are supplied by the panel line, which is also a separate department.

2.1. General Yard Layout

The guiding principle is logical material flow. This is facilitated by allowing adequate road-

ways for transporters and other vehicles, such as forklifts, mobile cranes, and center lift carriers. Personnel traffic should be separated from industrial traffic and provision made for personnel transport from parking areas located away from the industrial part of the yard. The perimeter of the shipyard

should be reserved for rail, barge, and truck delivery of raw materials and interim products that were built at other shipyard facilities or by subcontractors. Parking and administration buildings should also be located on the perimeter to avoid interference with material delivery.

Larson proposes a newbuilding yard, shown in Figure 5-9.[4] This is an idealized fourth-generation shipyard. Many of the principles are the same as for a product-oriented shipyard. In the idealized newbuilding yard, shops are placed around the building dock in a U shape, with pre-outfitting areas immediately adjacent to the building dock. This is an example of a basic difference in philosophy between the third-generation process type shipyard and a yard fully applying group technology. In the former, pre-outfitting is treated more as the exception, and special provisions are made for it. In the latter, zone outfitting is the standard, and the total yard layout is based on integrated hull block construction, zone outfitting, and zone painting.

In the yard shown in Figure 5-8, approximately 50 percent of outfitting is on-unit and another 30 percent on-block. Outfitting on-unit is accomplished in the shops and on-block outfitting is integral to block assembly. Covered block assembly areas are located adjacent to the erection area (assembly yards Nos. 2, 3, and 4). Typically, storage space for 60 percent of the blocks that compose a ship commonly built at a shipyard is required close to or around the building position. Process lanes employing actual or virtual work flow are used to organize the work at each manufacturing level. Specific geographical locations in the shipyard, including platens, shops, and other work areas, compose the various process lanes. Process lanes will be discussed in more detail later in this chapter.

For clarity, the proposed newbuilding yard shown in Figure 5-9 does not include a repair facility. One of the factors contributing to the failure of many modern third-generation

shipyards was specialization. When the demand for their highly specialized product collapsed, the lack of flexibility made switching to other markets difficult. Repair and overhaul provide a somewhat stable source of work for shipyards, and thus the capability of performing this type of work can add to long-term profitability. Consequently, repair and overhaul capabilities are likely to be included in the fourth-generation shipyard. Additionally, diversification and the ability to adapt to different product lines when the demand for ships is slack is inherent in group technology shipbuilding. In its planning, one U.S. shipyard carries the philosophy of diversification further. Its long-range plan calls for: (1) subcontracting pipe and heavy steel construction for petrochemical, power plant, and other similar industries; and (2) other maritime construction, such as drilling rigs [5]

2.2. Building Positions

The traditional building position for ships are longitudinal sloped building ways or shipways (see Figure 5-10). The vessel is built on blocks and other supports. Just prior to launching, support is shifted to stationary ground ways and sliding ways positioned above the ground ways. Additional temporary supporting structures, called cradles and poppets, are also installed. At launching, release mechanisms are used, permitting the vessel to slide

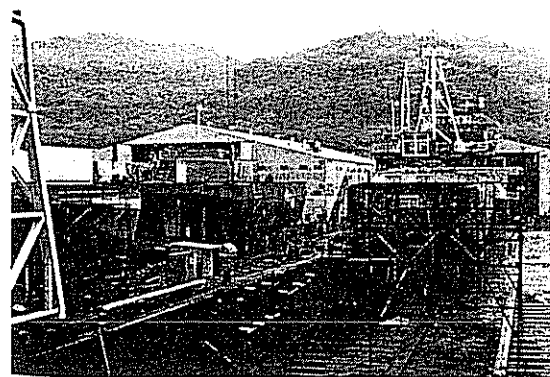


Fig. 5-10. Longitudinal-sloped building ways (courtesy Tacoma Boatbuilding).

down the ways into the water. Ships are commonly launched stern first on longitudinal shipways. Detailed arrangements and computations are required to assure launches do not damage the new vessel. The disadvantages of conventional sloped shipways, primarily in terms of aligning blocks, were discussed previously. Alternatives include graving docks, side-launch shipways, or erecting the ship on land-level building ways and moving it to a floating dry dock or ship lift for launch.

Graving docks are permanent structures totally excavated from existing land or built up by dredging and depositing material (sand, rock, and concrete) along the sides of the dock area (see Figure 5-11). End gates are either hinged or floating. The former are hinged at the bottom and usually have a buoyant chamber at the top to facilitate opening and closing. When a ship is being launched, the dock is flooded and the end gate is opened. The buoyant chamber is also flooded, enabling it to sink to the bottom in the open position to permit the vessel to float out of the dock. The floating or caisson end gate is buoyant. As the dock is flooded during launching, the end gate is disconnected, deballasted, and floated free, permitting the vessel to depart from the dock. The procedures are reversed for securing the end gate prior to dewatering a graving dock. Guillotine gates are generally used for intermediate positions to permit flooding of part

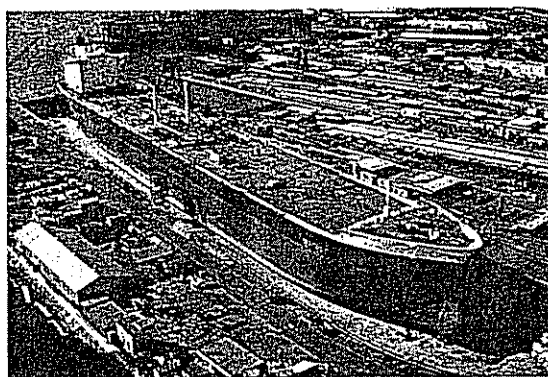


Fig 5-11. Graving dock (courtesy National Steel and Shipbuilding)

of the dock independent of the remainder. These gates are positioned by crane and, as the name implies, are dropped into slots in the sides and bottom of the dock.

Graving docks have many advantages. One, of course, is size, which is nearly unlimited. Another is the level building position. However, they are subject to stringent environmental controls because of the extensive earth removal required during construction of the dock and the danger of water pollution during its operation. They are also expensive; cost is highly dependent on the local bottom composition. Additional disadvantages are:

- during flooding, all material and equipment must be removed
- moving material, equipment, and workers in and out is significantly more expensive than with land-level building ways
- the dock cannot be marketed independently of the shipyard, should demand decrease or not meet expectations
- docking and undocking are relatively slow, compared to other systems

Side-launch systems are particularly well suited where conventional stern-launching shipways would be very steep or where there is insufficient open water for stern launching (see Figure 5-12). Side-launch ways have the advantage of the ship's being level during erection. As in longitudinal shipways, vessels are built on blocks and the weight shifted to ground ways and sliding ways just prior to launch. The ground ways consist of a fixed portion and a tilting portion, which permits the vessel to tilt sideways and slide into the water. Mechanical triggers are commonly used to begin a side launch.

Some yards use a system of building ships on level ground and transporting them on rails to a dry dock for launching. The same dry dock can be used for docking after test and trials. Where the dock is parallel to the

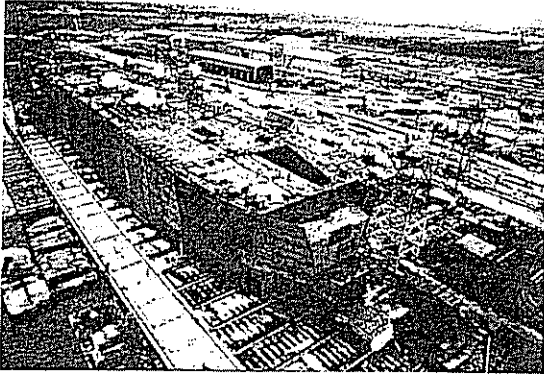


Fig 5-12 Side-launch ways (courtesy Avondale Shipyards)

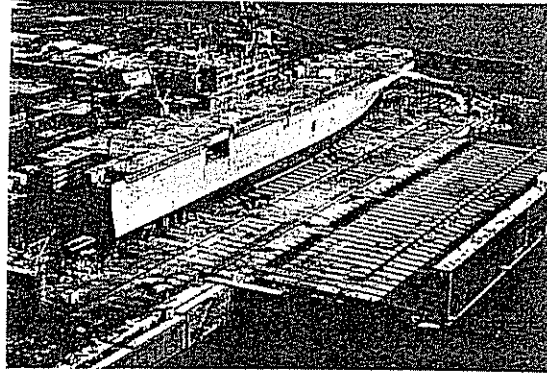


Fig 5-13 Floating dry dock with removable wing wall (courtesy Ingalls Shipbuilding)

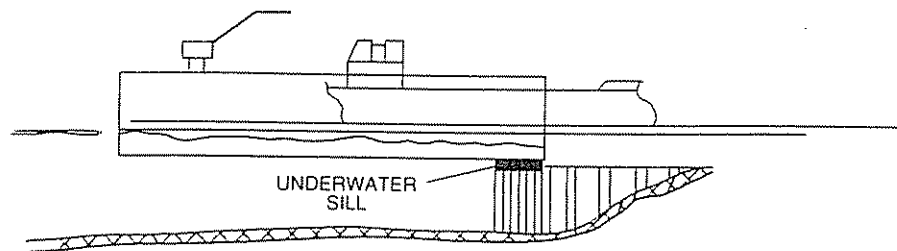


Fig. 5-14. Floating dry dock with heavy-lift translation system.

erection area, the landward wing wall is removed and the dock is supported by a grid adjacent to the pier while the ship is being moved onto it. The wing wall is then replaced and the dock moved away from land to clear the grid for launching. A system like this (see Figure 5-13) is employed at the shipyard shown in Figures 5-4 and 5-5.

A similar dry dock (or a launch pontoon, as it is commonly called) could also be nosed into the pier, particularly in an area where space and currents are not limiting factors. This configuration is shown in Figure 5-14. As with the parallel launch pontoon, the end of the floating dry dock could be rested on an underwater sill or grid for stability while the ship is moved on or off. One distinct advantage of a floating dry dock is that it is considered to be a ship by most port managers and can operate outside the shipyard area.

A similar concept but with a different launch/docking device has been used by some

shipyards. The device, called a ship lift or synchrolift, is used in conjunction with a transfer system which can move the ship to and from a land-level work area serviced by jib cranes (see Figure 5-15). The lift itself is a vertical elevator. It consists of a platform, on which a cradle is mounted, and either chain or cable lifting devices which raise or lower the platform vertically. Ship lifts are relatively new and have in the past been used only for smaller vessels. Ship lifts capable of launching large commercial ships are a recent development. A similar approach, with or without the transfer capability, is used for construction and launching of submarines (see Figure 5-16a) and smaller vessels built entirely in enclosed shops (see Figure 5-16b).

2.3. Material Handling

The adoption by many yards of heavy-lift surface transporters represents a major change

in material-handling equipment over the past two decades. This followed the introduction and growth in size of modules. Because of

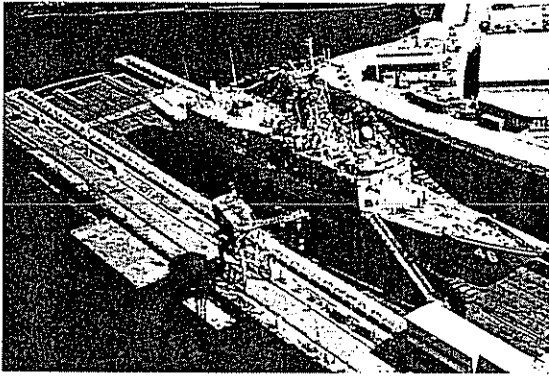


Fig. 5-15. Synchrolift (courtesy Todd Pacific Shipyards, Los Angeles Division).

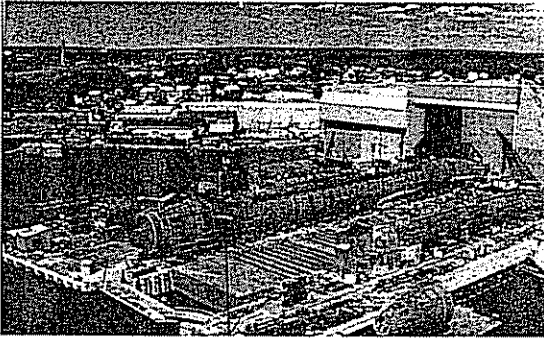


Fig 5-16(a)

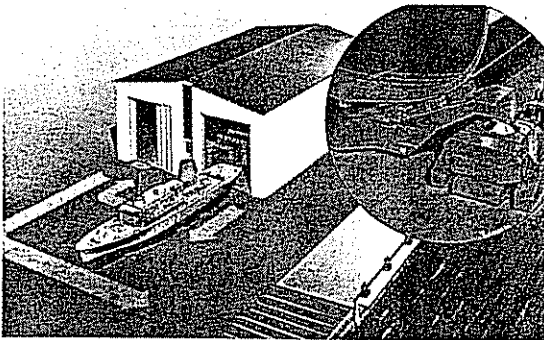


Fig 5-16(b)

Fig 5-16. Level building launch facilities. (a) Submarine launch facility (courtesy General Dynamics, Electric Boat Division). (b) Small ship translation and launch facility (courtesy Total Transportation Systems and Marinette Marine)

their low profile, transporters are well suited for the movement of completed blocks and deckhouses to enclosed blast and paint facilities. They are also used to move blocks between platen areas, where the blocks are assembled and outfitted, to block storage areas, located close to the erection berths.

Large-capacity gantry cranes are commonly used to load outfitted blocks into the building berths. In addition to the use of gantry cranes over building berths, gantry and bridge cranes are used extensively in steel stock areas, prefabrication and fabrication shops, and assembly platens. Steel stock yards are normally served by a wide-span gantry crane fitted with a magnetic fixture for moving the material to storage or to a conveyor system. The conveyor system moves steel through the panel line. A blast and primer system is usually incorporated into the conveyor system. This conveyor system will then deliver material to the feed rolls of the primary cutting machines. The material will then progress through the cutting, forming, and subassembly areas of the shop, emerging from the building onto the panel line or main assembly platens.

The yard shown in Figure 5-8 has a similar arrangement of gantry cranes and a conveyor feeding into the blast primer facility and then into the parts fabrication shop. Gantry and bridge cranes, besides being able to move loads transversely as well as longitudinally along a process line, are particularly well suited for covered work areas. The percentage of covered area for each production stage at this yard is shown in Table 5-1. [3] A high percentage of covered area even in temperate climates is an apparent trend for modern shipyards, both in the United States and abroad.

2.4. Warehousing Facilities

In many group technology shipyards, warehousing, pallet preparation, and all transport equipment are the responsibility of the mate-

Table 5-1 Sample percentage of covered area by production stage for a product-oriented shipyard

Production Stage	Percent Covered
Steel storage	0
Parts fabrication	100
Assembly	65
Outfitting	35
Warehousing	65
Launch ways	0
Total excluding steel storage and launch ways	62

rial control group. Pallet preparation is frequently performed in the shops by shop personnel as a collateral function. However, the material control group is still responsible for the timely preparation and delivery of pallets. Many sophisticated automated warehouse storage and inventory systems are in operation throughout the industry. However, of those U.S. shipyard facilities plans reviewed, no mention is made of adopting such systems. The main point made in most facilities plans is that warehouse facilities should be located adjacent to the shops which use the material. Depending on distances involved and assuming an adequate transportation network, a central warehouse might also be desirable (see Figure 5-17). However, with computers handling storage and retrieval and accounting for inventory, several dispersed warehouses can be operated as a single integrated system. The primary consideration is that tight control of inventory and delivery must be maintained. In group technology shipbuilding, the warehousing group plays a primary role in executing the production schedule. They must therefore have the tools to keep track of both schedule and material.

2.5. Production Facilities

Shipyard facilities layout cannot be considered independent of automation. However,



Fig. 5-17. Warehouse facility (courtesy Newport News Shipbuilding)

automation and capital intensiveness are economic decisions which must depend on market analyses and company objectives. In general, the cost of automation and capital intensiveness is the price that must be paid to reduce required work area and to improve accuracy and reduce rework.

Capital intensiveness can often reduce flexibility. Third-generation process type shipyards provide examples of this. A tradeoff which is made in group technology shipyards with considerable success is the use of line heating instead of mechanical rolls and presses. Line heating is more labor intensive; however, the flexibility it provides often results in line heating being a low-cost alternative for many applications, compared to the purchase and use of capital equipment.

2.5.1. Mold Loft and Marking. The advantages of 1/10th-scale lofting and computer-assisted lofting cited in Section 1.3 of this chapter are applicable to group technology yards. Modern computer-aided design (CAD) systems have become the standard in nearly all modern shipyards. These systems often include automatic marking capability. Numerically controlled (N/C) plate marking is accomplished

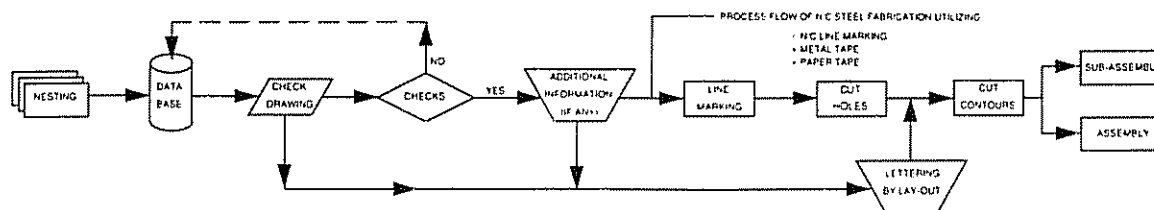


Fig 5-18. Flow diagram of N/C steel marking process

by burning zinc or plastic powder onto a plate to form a continuous 1/16 (1.6 mm) inch-wide line. This method can mark a continuous line at the rate of 40 feet (12.0 m) per minute. Figure 5-18 is a flow diagram of N/C steel parts fabrication using N/C line marking. [3] Other automatic marking systems, such as punch marking, are also employed.

2.5.2. Cutting and Edge Preparation. Material to be N/C cut is generally chosen because of its difficulty in burning and layout. Numerically controlled burning is generally used for processes requiring high precision and for plates cut repetitively from the same N/C tape or data. Table 5-2 is an example of recommended cutting methods for different categories of steel parts. [3] Note that these recommendations were made for a specific shipyard. However, the machines listed and the reasons for each selection are instructive and should give the reader insight into available equipment and selection criteria.

2.5.3 Panel Line. A typical layout and flow pattern for a curved panel parts fabrication and subassembly shop (Shop 1) and a panel line (Shop 2) for flat panel parts fabrication and subassembly are shown in Figure 5-19 [3] Plate enters the plate staging areas from a combined shotblast and primer facility. Numerically controlled burners feed the curved panel subassembly and flat panel lines. Vertical stiffener storage is provided on racks adjacent to the panel line.

Seam welding of shell plate panels for bottom shells, side shells, deck plates, and

bulkheads is performed in the assembly shop. Space for egg-box assembly of transverse and longitudinal framing is also provided. Assembly of tank tops to tank bottoms on a double-bottom unit is also performed in the shop. For a larger shipyard, the panel line could be broken into two facilities. Each could then specialize by problem area, one in tank bottoms and the other in tank tops, for example. Plates are transported to the panel line shops by low-profile transporter, bridge crane, rollers, or chain conveyor, and stored at the shop entrance. Plates are moved from the shop entrance to either panel line using conveyors. The panel assembly method is described as follows.

- **Plate Fitting:** Plates are moved by rollers and chain conveyors to the fitting station, where they are fitted together manually and tack welded. Standard size runoff tabs are added at the seams.
- **Plate Welding:** The panel is then conveyed to the seam butt-welding station where adjustable copper backup bars are positioned according to the width of the plates. A line of magnets on each side of the backing bar holds the plate down on the conveyor bed. The backing bar is forced against the seam by air pressure. Flux is automatically supplied by the welding machine and removed manually after the welding is completed. The machines can weld up to three seams simultaneously, in plates up to one inch (2.5 cm) thick,

Table 5-2. Recommended cutting methods for steel parts

CUTTING STAGE	CATEGORY OF PIECES	EFFECTIVE CUTTING MACHINE	METHOD	RECOMMENDED SELECTION	
Long'l & FB	Long'l	Automatic Long'l cutting machine & semi-automatic machine	Butt: Automatic Long'l Cutter Slot Hole: Semi-automatic machine	X	1 Auto machine is not completely implemented 2 Auto machine is not cost-effective due to low volume
		Manual & semi-automatic machine	Butt: Manual Slot Hole: Semi-auto machine	O	
	Flat bar	Automatic Long'l cutting machine & semi-automatic	Butt: Automatic Long'l cutter Slot Hole: Semi-auto machine	X	
		Manual & semi-automatic machine	Butt: Manual Slot Hole: Semi-auto machine	O	
Curved Plates	Curved Plates	NC Gas Cutter	NC Marking ———> NC Gas Cutter	O	1 Because of few manhours
		Semi-automatic machine	Manual Marking ———> Semi-auto machine	X	
Internals	Floor & Long'l Bhd with little edge preparation or no edge preparation	NC Plasma Cutter	NC Marking ———> NC Plasma Cutter	O	1 Because of more accuracy 2 Because of few manhours
		NC Gas Cutter	NC Marking ———> NC Gas Cutter	O	
		Semi-automatic machine	EPM-Marking ———> Semi-auto machine Photo-Marking ———> Semi-auto machine Manual-Marking ———> Semi-auto machine	X	
	Floor & Long'l Bhd with edge preparation	NC Gas Cutter	NC Marking ———> NC Gas Cutter	O	In Japan, O and X are reverse. But in U.S., NC Gas Cutter is better due to awkward manual cutting & less investment.
		Semi-automatic machine	EPM-Marking ———> Semi-auto machine Photo-Marking ———> Semi-auto machine Manual-Marking ———> Semi-auto machine	X	
	Small Pieces	NC Plasma Cutter	NC Marking ———> NC Plasma Cutter	O	More speedy and less shrinkage than NC Gas Cutter In U.S., manual cutting is awkward
		NC Gas Cutter	NC Marking ———> NC Gas Cutter	A	
		Semi-automatic machine	EPM-Marking ———> Semi-auto machine Photo-Marking ———> Semi-auto machine Manual-Marking ———> Semi-auto machine		
	Small pieces which are usually cut out from scrap	Optical Tracer		O	
		NC Plasma Cutter	Small pieces are put in between big pieces After big pieces are cut. They are manually or automatically cut	O	
		NC Gas Cutter		O	
		Semi-auto machine	Manual-Marking ———> Semi-auto machine	X	
Panel	Panel Plate	Flame Planer	Manual-Marking ———> Plane cutter EPM-Marking ———> Plane cutter Photo-Marking ———> Plane cutting	O	Manual marking because of low manhours
		Semi-automatic machine	Manual-Marking ———> Semi-auto machine	X	

O: Suitable; A: Fair; X: Unsuitable

with one pass. One-sided submerged arc welding by the flux, copper-backing (FCB) process is utilized to weld plates at the panel line.

- **Marking and Cutting:** Plate is marked and cut to size at this station. Marking of panels is done after welding to allow for neat cutting (i.e., to exact dimensions) of the panel. After a panel has been welded, stiffener locations are

marked. Cutting of deck openings, etc., is also carried out at this stage using semiautomatic and manual flame cutting equipment. The panels are then moved to the next station along the assembly area by crane.

- **Egg-Box Assemblies:** In conjunction with the panel assembly, and alongside it, is another conveyor line where longitudinals and transverse frames are posi-

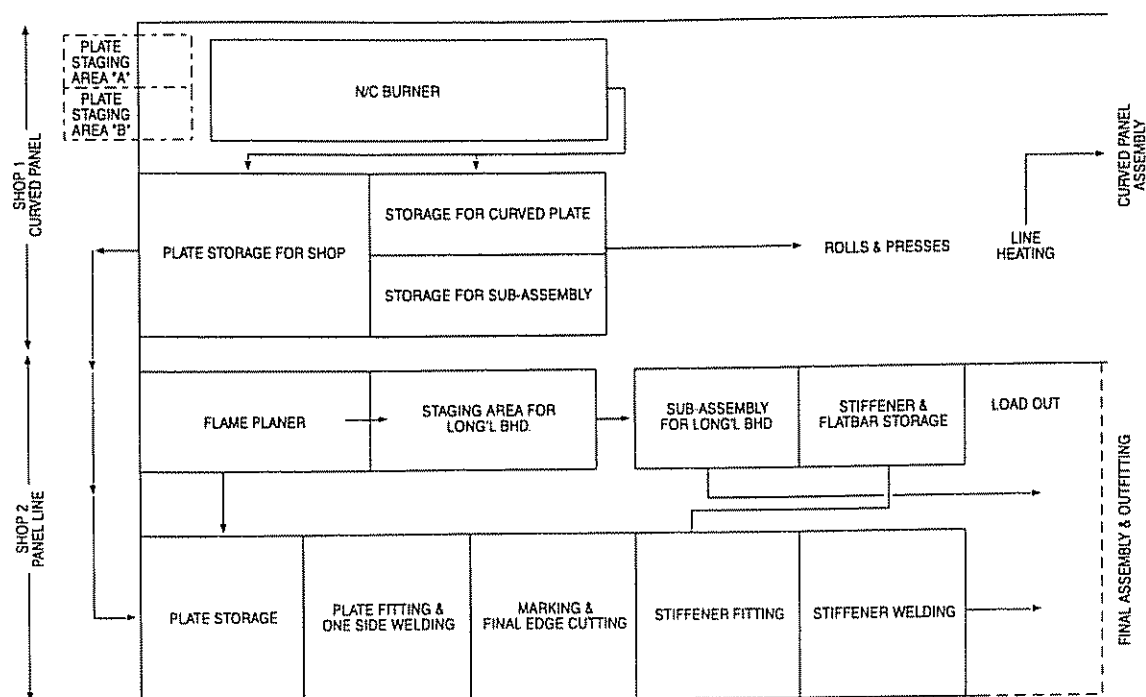


Fig 5-19. Typical layout of a steel curved panel shop and panel line.

tioned. These are fitted together into egg-box assemblies using an arrangement of lugs and jigs ready for positioning onto the panels by crane.

- *Stiffener Setting:* The normal flow of panels is a straight line through the shop. Panels receive stiffeners which are set into place manually using a crane as they proceed down the conveyor.
- *Stiffener and Egg Box:* The stiffeners and egg-box block assemblies are welded using gravity or automatic methods. Figure 5-20 is an automated stiffener welder used at a U.S. shipyard. If required, the block is turned over at this stage and any remaining welding is completed.
- *Repair:* Welding checks are made at the exit end of the shop, and any final repairs are performed here. In addition, outfitting work such as pipes, ladders, and grating, as well as scaffold brackets,

lifting pads, anodes, stabbing guides, etc., are installed and welded at this point. Painting is also carried out here and the finished block is then transferred directly to a block storage area or to erection. A special repair area could be incorporated into a prior stage. The area designated for repair may be recessed below the adjoining flooring to provide room for making repairs from the underside of the panel. This eliminates the need to turn the panel over.

There are many variations to the description provided above. Specific layouts and work organization depend on the particulars of the shipyard, including markets, product mix, existing equipment, worker skill, and other factors. The general principles, however, are similar. Figures 5-21 and 5-22 show schematics and photographs of two different panel lines.

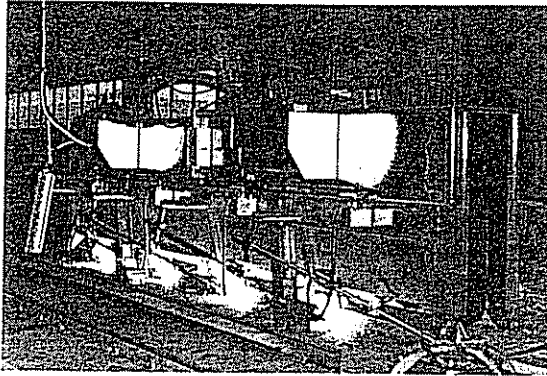


Fig 5-20. Automatic stiffener welding (courtesy Total Transportation Systems).

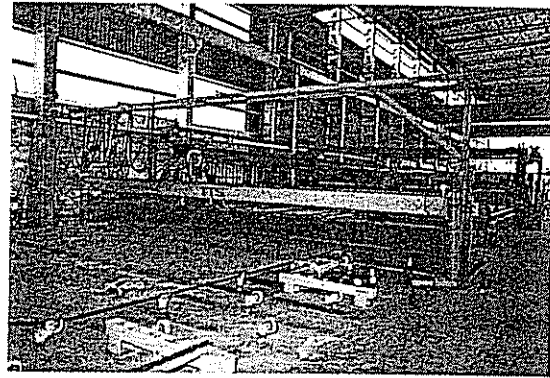


Fig 5-21(a). Large shipyard steel panel line in operation (courtesy Total Transportation Systems).

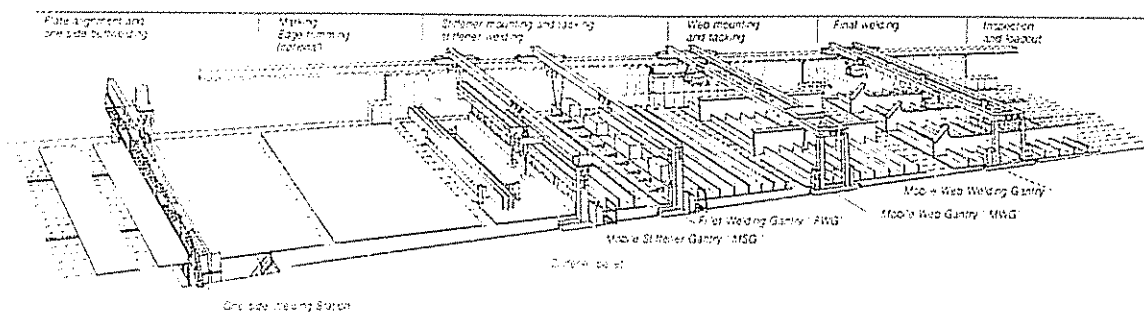


Fig 5-21(b). Larger shipyard steel panel line schematic (courtesy Total Transportation Systems)

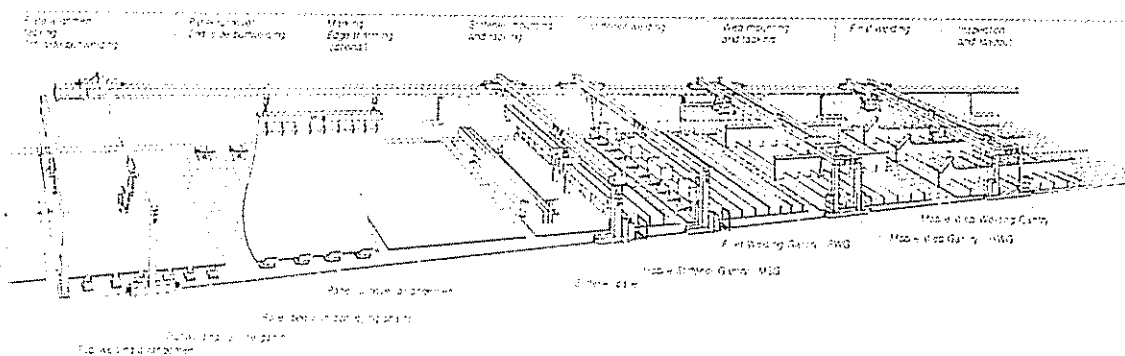


Fig 5-22(a). Shipyard steel panel line schematic (courtesy Total Transportation Systems).

2.5.4 Blasting and Painting. Most blasting operations are carried out in enclosed spaces in order to comply with environmental standards and to permit grit recycling. Some painting may also be done in enclosed spaces

Surface preparation and coating are accomplished (1) prior to the parts fabrication stage, (2) as a stage in on-unit outfitting and on-block outfitting, and (3) during erection (on-board outfitting). Finish painting is generally

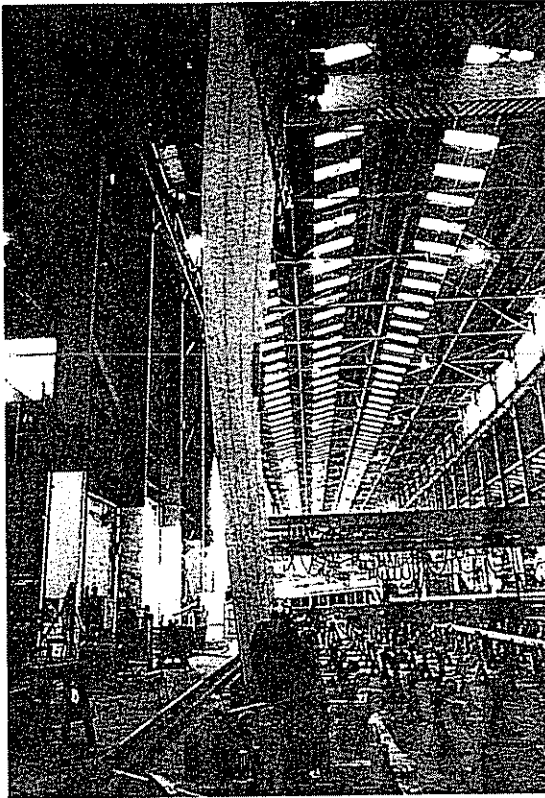


Fig. 5-22(b) Shipyard steel panel line in operation (courtesy Total Transportation Systems and Pennsylvania Shipbuilding)

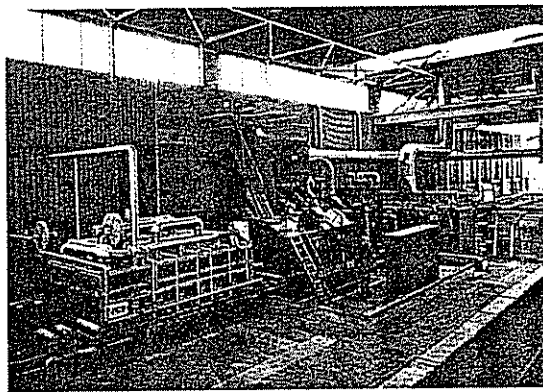


Fig. 5-23. Panel line blast and coat facility (courtesy Total Transportation Systems)

accomplished at the earliest stage consistent with welding schedules.

- *Parts Fabrication Shop:* Material to be surface treated is generally transferred

to the shop by crane and/or conveyor system from the stock yard. Treatment is applied in accordance with a paint schedule within prescribed specifications. The painting sequence is based on the cutting schedule, which ensures a constant flow of material through the area. Material flows from the incoming conveyor, through a preheat furnace, the horizontal shotblast machine, a painting station, and down an inward-sloping conveyor to the marking or cutting station. Steel plate is processed in a horizontal position through the machine and is blasted and coated on both sides simultaneously. Structural steel to be shot-blasted is processed similarly. Figure 5-23 is a photograph of parts fabrication shop blast and paint equipment.

- *Block Surface Preparation and Painting:* Primer and finish coats are applied at each stage of block assembly. Additionally, some shipyards have special painting buildings for final painting. These buildings may have removable roofs to facilitate the movement of blocks. They are normally equipped with mechanical cherry picker type staging. In general, block surface preparation and coating would follow the completion of most of the hot work on the block, but precede the installation of outfit materials that are subject to damage from blasting operations. Tradeoffs are required to determine the amount of outfit-related hot work accomplished prior to block surface preparation and coating versus the need to repair or touch up paint damage by such work that must be done after block coating.

Figure 5-24 shows a typical layout of a block surface preparation and painting shop. [3] Such a shop may be used for painting all types of assembled blocks, particularly for

- | | |
|-----------------------|--------------------|
| 1 HEATED AIR UNIT | 6 USED SAND HOPPER |
| 2 DUST COLLECTOR | 7 HEATED AIR DUCT |
| 3 CLEAN SAND HOPPER | 8 EXHAUST DUCT |
| 4 CLEAN SAND CONVEYOR | 9 HEATED AIR UNIT |
| 5 SAND COLLECTION PIT | |

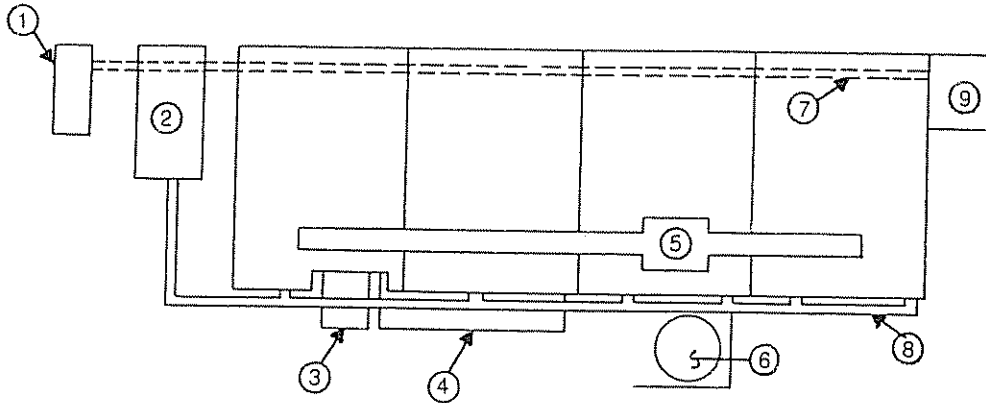


Fig 5-24 Typical layout of a block surface preparation and coating facility

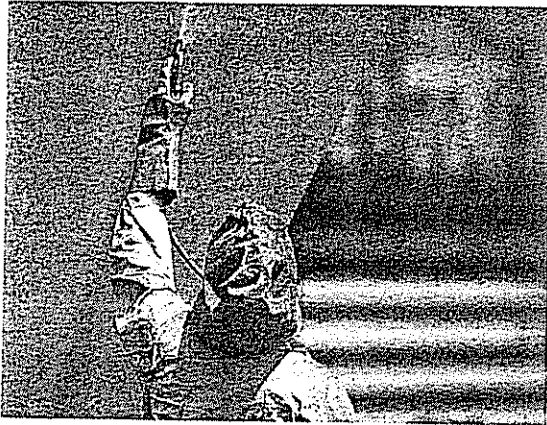


Fig 5-25. Erection site painting (courtesy Avondale Shipyards)

vessels with special painting requirements, such as gas or naptha product carriers or chemical tankers. The building shown consists of four separate rooms but has a sliding roof, so that one of the rooms is always open. Such facilities commonly provide multiple capabilities, including blast and coating equipment, special heating, ventilation, and air-conditioning equipment, and systems for delivering and recycling or removing blast abrasives. The ability to move large blocks is an important aspect of such facilities.

- *Erection Site Painting:* Touch-up and final-coat painting is performed on-board at the erection site (see Figure 5-25). Painting at erection is performed according to the erection schedule. As is the case in all aspects of group technology shipbuilding, the goal is to move as much work as possible to earlier manufacturing levels. Since final painting often is one of the last stages of the shipbuilding process, efforts are made to minimize the amount of painting work required at erection and following launch.

2.5.5 Pipe Fabrication. Significant automation in pipe fabrication is rare in shipyards. Apparently demand for pipe does not usually justify the expense involved in building a capital-intensive pipe facility. The processes and individual pieces of equipment employed in most shipyard pipe shops were described in Chapter IV.

The layout and flow of work in a pipe shop incorporating a mix of manual and semiautomated methods is shown in Figure 5-26. [6] Pipe fabrication work is performed in sepa-

welding of pipe sections, up to 18 feet (5.5 m) is processed by the following N/C machines:

- *Assembly Stage*
 - Flange robot
 - Flange bolt hole detector
 - Flange checking machine
- *Welding System*
 - Welding torches: four-point simultaneous welding

Pipe to be bent is gravity fed to a conveyor and sent to a buffer station beside the pipe-bending machines. These N/C machines are automatically set for bend angle, start points, and turn angle. Two pipe benders are available for bending small pipe:

- Type 2: 2-inch schedule 40 capacity
- Type 4: 4-inch schedule 20 capacity, but only used for pipe up to 2½ inch (6.4 cm) diameter

The above machines are located in the automatic fabrication area. A section designated as a manual fabrication line refers to the handling methods, e.g., by gravity roller conveyor, jib crane, or trucking, as well as to the equipment used. However, some of the equipment used in this area is automatic.

Two pipe coasters are used for cutting pipe to be joined by branch pipes. One coaster is located in each of the small and the large pipe-fabricating areas. Capacity of the machines is for 8-inch (20 cm) and 12-inch (30 cm) diameter pipe, respectively. These machines are capable of automatically cutting holes for saddle branches. Manual welding methods are employed on the small pipe fabricating side of the shop. A press roller is used to hold and rotate pipe for manual welding.

The section of the shop used for fabricating large pipe has some automatic equipment, but utilizes mostly manual handling and transporting methods. A gas cutting machine cuts and bevels pipe while it rotates

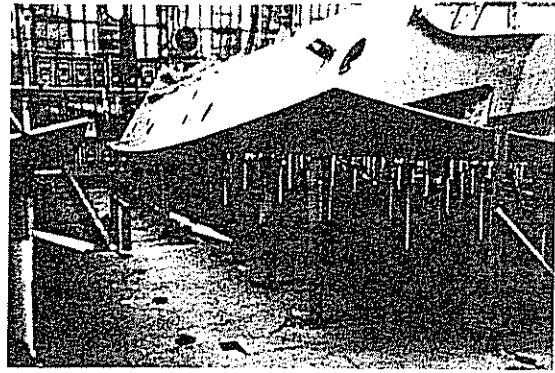
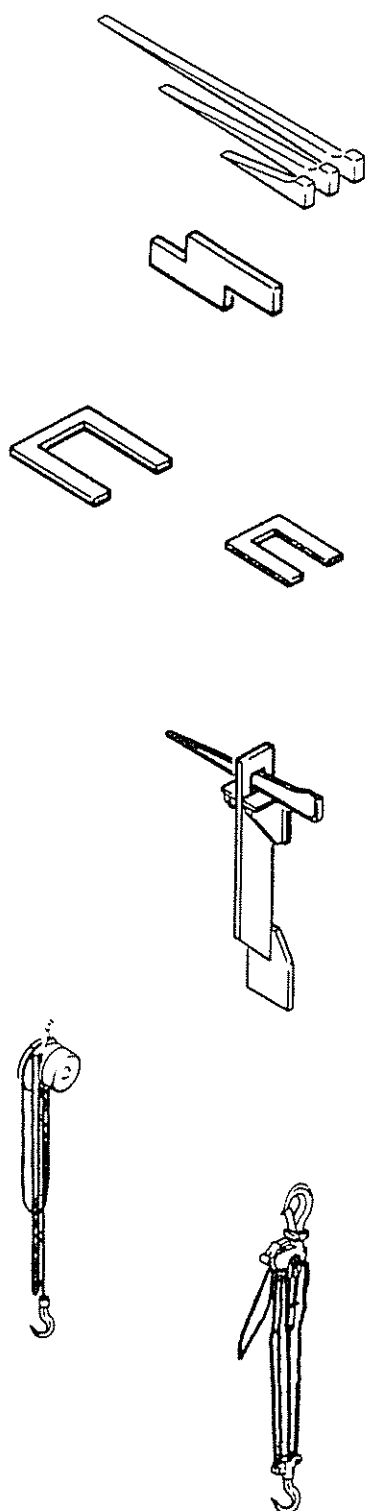


Fig 5-28 Pin jig.

on a roller mechanism. The larger pipe coaster (for 12-inch pipe) is used in this area. Automatic CO₂ gas-shielded arc welding machines capable of welding pipe up to 24-inches (60 cm) diameter are used in the large pipe area. These machines can weld four points simultaneously while the pipe is rotated by a roller.

Working manuals specify the requirements to be met in all pipe fabrication techniques. This includes such items as welding specification, bending methods, penetration piece designations, finishing requirements, surface treatment, and pipe flushing standards. Bending is generally by the cold bending machine and high-frequency induction bender. Hot bending may be applied as a special case if necessary. A hot process is also used for adjusting pipe alignment. Miter bends may be used only for low-pressure pipes, such as exhaust steam, seawater, and exhaust gas piping.

Raw material for pipe fabrication, together with the appropriate engineering data, flows to the pipe shop in a precise and controlled manner. The pipe is fabricated, bent, flanged, and made ready for allocation to a specific pallet. The material is then held in pallets until required at a specific time at a particular outfitting area. As for group technology yards generally, palletizing and on-unit pipe fitting are accomplished in or adjacent to the pipe shop.



WEDGE DEVICES

WEDGE, a piece of hard material, as wood or metal, tapering from a thick board to a thin edge that can be driven or forced into a narrow opening. Shipyard wedge configurations are usually made from one-inch-thick steel plate and are typically 12 and 17 inches in length.

STEP-CUT DOG, also known as dog, a metal device used for holding or backing the force applied by a wedge or other tool. This device is attached by welding. Shipyard uses include erecting and aligning hull deck and bulkhead plating.

WELD-ON SADDLE, also known as "U"-dog yoke and hairpin, a "U" or "L" shaped metal device used in conjunction with a wedge to straddle and hold one part to another. Shipyard uses include attachment of stiffeners to plate material.

PULLDOWN, a metal device welded or mechanically fastened to the part at one end and slotted at the other, used in conjunction with a wedge and anchor clip to pull one part toward another. Shipyard uses include pulling deck or shell plating and other components together.

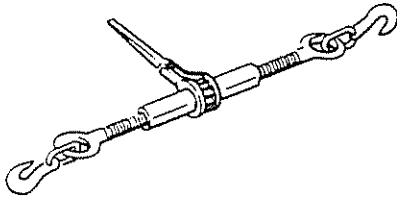
GEAR-PULLEY DEVICES

CHAINFALL, also known as chain hoist, a device having gears and pulley(s) and operated by chain to obtain mechanical advantage in lifting or pulling. Shipyard use includes areas where long reach or stroke is required in pulling parts together.

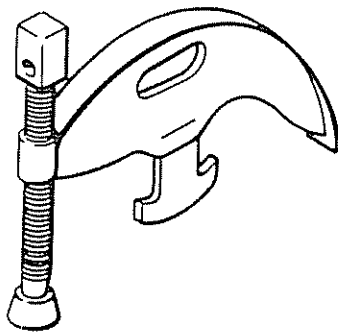
COME-ALONG, a device having a ratcheting gear-pulley arrangement to change the effective length of a chain for lifting or pulling. Shipyard uses include pulling parts and assemblies together.

Fig. 5-29 Typical shipbuilding jigs and fixtures (continued on following pages)

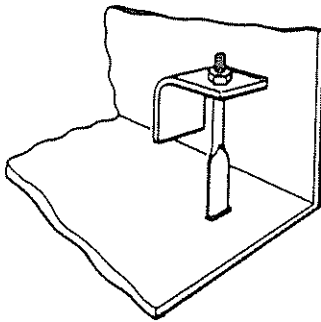
THREADED DEVICES



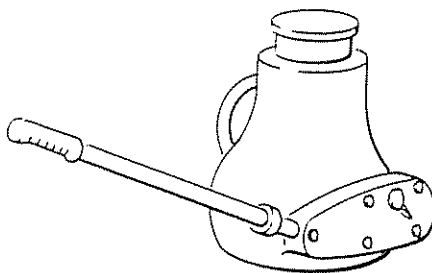
PUSH-PULL JACK, also known as steamboat jack and ratchet jack, a device having a ratcheting sleeve with opposite internal threads at each end or with an internal thread at one end and a swivel at the other. The effective length of the device can be changed by rotating the sleeve or swivel. Shipyard uses include areas where short reach or stroke is required in pulling parts together.



JACKING CLAMP, any number of devices which are hooked or welded having a screw at one end to apply force for aligning and fairing. Shipyard uses include fairing and aligning plate and occasionally used to clamp down stiffeners.



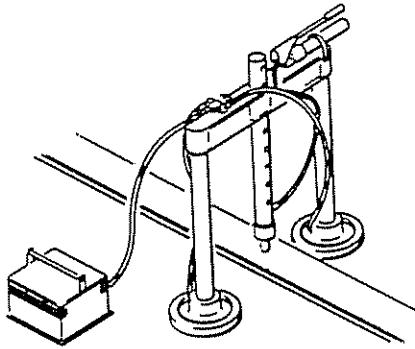
CLIP AND BOLT, a device consisting of an angle support and a headless bolt, and used to pull parts toward each other. The angle support and bolt can be welded or mechanically fastened. Shipyard uses include pull bulkhead and stiffener-to-plate or deck.



HYDRAULIC DEVICE

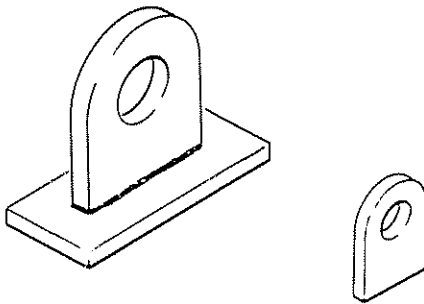
HYDRAULIC JACK, also known as buda jack and bottle jack, a hydraulic and geared device having a single or double acting cylindrical piston used for hoisting or lifting. Shipyard uses include fairing, lifting and holding parts together that require short reach or stroke.

Fig 5-29(b)



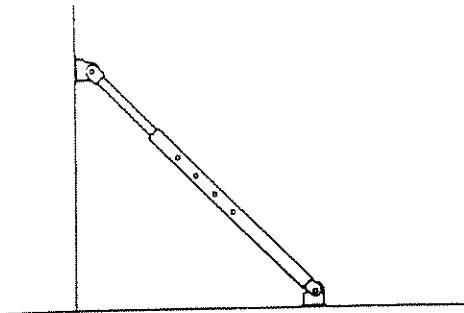
PNEUMATIC DEVICE

VACUUM SADDLE, also known as vacuum jacking clamp, an air operated device having suction pads for gripping relatively smooth surfaces and a "U" or "L" shaped metal structure for straddling and holding parts together. This device is used in conjunction with a screw and thread or hydraulic ram for applying pushing force. Shipyard uses include stiffener-to-plate attachment.

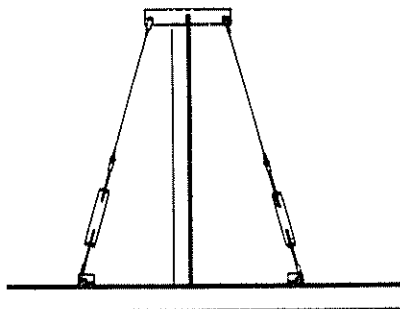


PADEYES, STAYS AND CABLES

PADEYE, also known as a doughnut, a metal device for use as an anchor, support and/or connector for lifting and applying force against. This device can be welded, clamped or mechanically fastened. Shipyard uses are numerous and include lifting, pushing, pulling, holding, aligning and fairing parts and components.

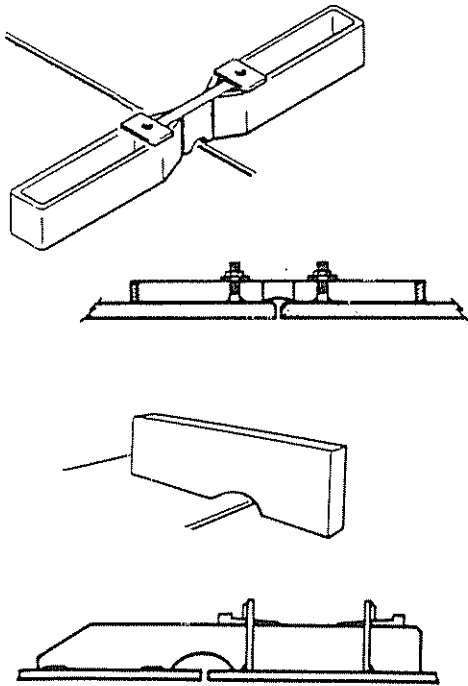


STAY, a strip of stiffening material used to hold, prop and/or support parts. This device can be welded or mechanically fastened. Shipyard uses include support and bracing of bulkheads and other assemblies to other parts.



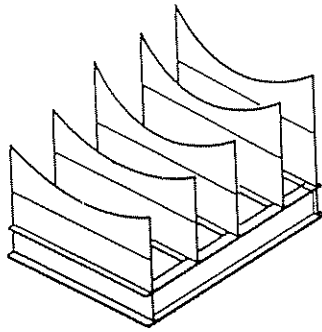
CABLE, a wire bundle or rope with means for attaching ends, used for lifting, pulling and holding parts. This device is normally attached by mechanical means to other lifting and fairing aids. Shipyard uses include lifting, supporting and transmission of pull forces for working components.

Fig. 5-29(c)



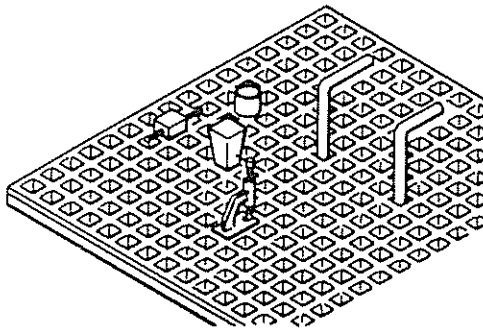
STRONGBACKS

STRONGBACK, any number of devices used to retrain applied forces and/or hold alignment. These devices may be welded or mechanically fastened and are used with many other tools for applying forces to parts. Shipyard uses include aligning, retraining, holding and fairing plates and structural components.



MOCKS AND FIXTURES

MOCK, a device which imitates the shape of an object for reference or support. Shipyard uses include holding hull shape and supporting units.



FIXTURE, a device used to hold, position and/or align a work piece for an operation or process. Shipyard uses include assembly, subassembly, foundation and part fabrication.

Fig 5-29(d)

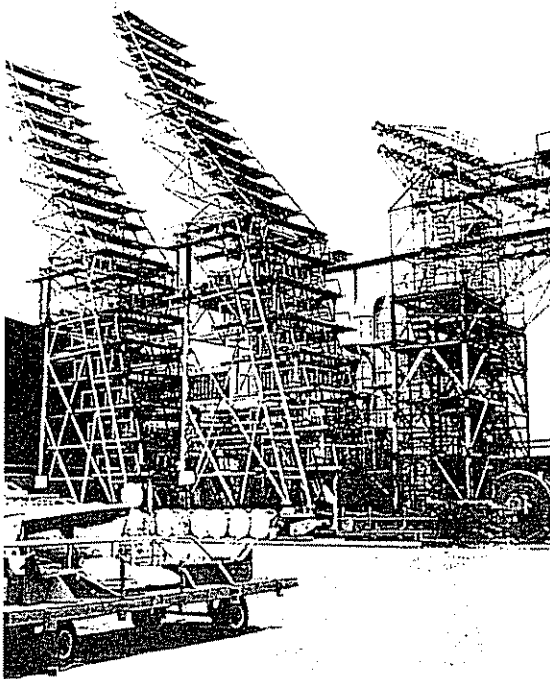


Fig. 5-30 Adjustable mobile scaffolding

2 5 6. Platens and Jigs. Steel platens are used throughout a shipyard. These are situated according to the process lane plan for the yard. Many jigs and fixtures have also been developed. The pin jig is perhaps one of the simplest but most effective pieces of equipment to be invented by modern shipbuilders. A pin jig, shown in Figure 5-28, is simply a series of vertical screw jacks which support curved blocks during fabrication. The jacks can be adjusted to attain the desired curvature. Prior to the invention and use of the pin jig, solid-welded steel jigs were manufactured for each curvature needed and scrapped after final use. The pin jig is an excellent example of a way to attain efficient production of individual ships. With welded jigs, efficiency is increased by series production, which increases utilization of each jig.

Figure 5-29 shows some of the many jigs and fixtures which have been developed or are used by shipbuilders [7]

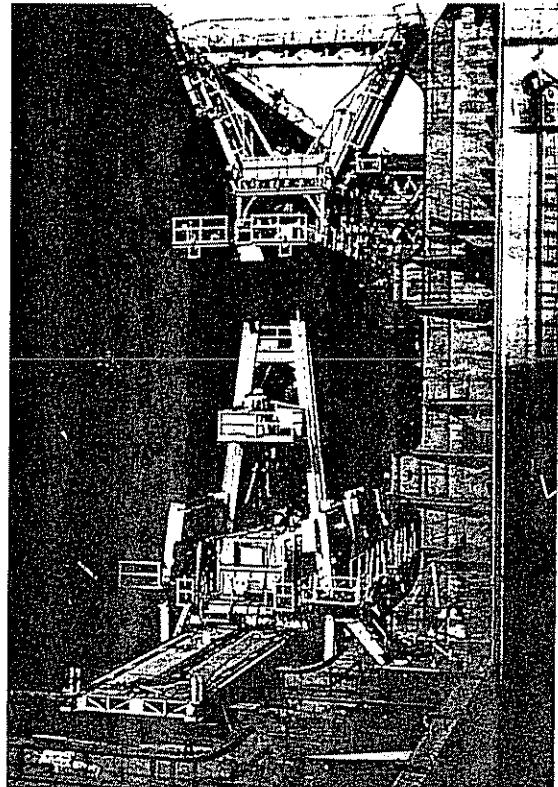


Fig. 5-31 Erection work unit.

2 5 7. Production Services. Production services include people movers, utilities, small tool and consumables storage, and staging. In addition, shipyards engaged in the overhaul and conversion of U.S. Navy ships must provide shore-side berthing and messing facilities.

Bus transport from parking areas has been mentioned. Other common people movers include bicycles and two- and three-wheeled, motorized vehicles. Some yards have escalators or elevators at outfitting piers and building docks.

Dockside and pierside utilities include electricity, potable water, fire main and raw cooling water, sewer service, compressed air, argon, oxygen, natural gas, and steam. Ideally all utilities are routed underground.

Small tool and stores such as electrodes, wire spools, etc., should be located for maximum convenience for the production groups consistent with security. Responsibility for

consumables may be delegated by the material control group to individual shops.

Staging is an area which offers a great deal of opportunity for cost savings in many shipyards. Assembly and disassembly of temporary staging is nonproductive work. Group technology shipbuilding systems attempt to eliminate temporary staging whenever possible. This is accomplished through design for production and painting at each assembly stage. Designing walkways into the structure, particularly in machinery and cargo spaces, has an additional benefit throughout the ship's life. Built-in staging can be used for operation, maintenance, and repair. Such built-in staging must, of course, be coordinated with the ship's owner.

3. Process Lanes

Group technology shipbuilding systems are based on the organization of work into distinct problem areas, using a product-oriented work breakdown structure. The shipyard facility should reflect this organization. The process lane concept marries the work organization and the physical plant. It also contains aspects of planning and scheduling, design, material control, and personnel organization. This section will concentrate on the reflection of the organization of work on the facility.

The process lane concept can be defined as "the categorization and separation of similar types of work, and the subsequent development of work centers specifically designed to efficiently perform that kind of work." Chapter III presented a work categorization scheme for shipbuilding (PWBS). Based on those concepts, work centers can be established to facilitate efficient production of the interim products. Keys to effective process lanes are planning, scheduling, and material flow. The goal of the system is to establish individual process lanes, each producing repeatable interim products, and each of which has a uniform work

Some staging will always be required inside building docks, painting facilities, and block assembly areas. Cherry picker type mechanical work baskets have been used effectively in shipyards for many years. Adjustable mobile staging, such as the unit shown in Figure 5-30, is also used, particularly where more than one person needs to work in close proximity on the same level.

Work units, such as the one shown in Figure 5-31, are used for erection. The tower type work unit is designed for erecting panels for longitudinal bulkheads and side shell. Safe walkways and all necessary fitting and welding machinery and services such as water and gas lines are built into the unit.

flow, both for an individual shipbuilding project and for multiple projects. This uniform work flow produces the least disruption of work and should result in a highly productive work station. Although the goal of uniform work flow at each process lane is not likely to be achieved, a number of strategies may be employed to increase the benefits obtained from the process lane organization. These will be discussed subsequently.

3.1. Physical Process Lanes

The choice of specific interim products and work centers to produce them is highly dependent on the characteristics of a particular shipyard. Included in these considerations are the product mix, existing facilities and capital equipment, and size, flexibility, skills, and training of the work force. The following example shall be used to describe a possible choice of physical process lanes.

Figure 5-32 presents the layout of a U S shipyard that adopted a process lane work organization [8]. This existing shipyard was reorganized to apply this concept. Six major block categories were chosen. Upon comple-

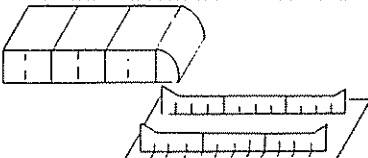
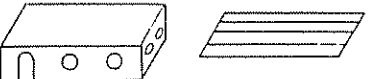
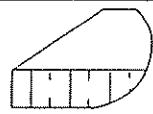
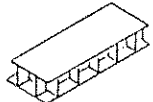
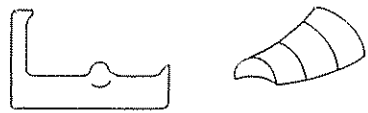
CATEGORY	BLOCK DESCRIPTION	PLATEN SUPPLYING FABRICATED PARTS	SHAPE	ASSEMBLY PLATEN
No 1 FLAT PANEL BLOCKS	MID PART DOUBLE BOTTOM SIDE SHELL LONG BHDS	23 24		20
No 2 CURVED SHELL BLOCKS	AFT AND FORE PART SIDE SHELLS	16		17
No 3 SUPERSTRUCTURE BLOCKS	DECK FLATS BULKHEADS HOUSES ETC	16		8 9 11
No 4 FORE PEAK AFT PEAK	LARGE AND HEAVY 3 DIMENSION BLOCKS	16		10 13 307
No 5 ENGINE ROOM INNER BOTTOMS	LARGE AND HEAVY INTRICATE BLOCKS	16		14 307
No 6 SPECIAL BLOCKS SKEGS RUDDERS	BULBUOUS SHAPES STERN CASTINGS	16		19

Fig 5-33. Platen/block categories.

tion of the blocks contained within each of these categories, the blocks are transported to the building position for erection. The six categories are (see Figure 5-33):

- flat panel blocks
- curved shell blocks
- superstructure blocks
- fore and aft peak blocks
- engine room innerbottoms
- special blocks

These block categories are supported by various subassembly and parts manufacturing categories. Additionally, outfitting on-unit, on-block, and on-board categories and similar blast and paint categories are integrated into the system.

The facility layout (see Figure 5-32) identifies the physical process lanes used to assemble the six categories of blocks. Category (1), flat panel blocks, comprises the largest number of blocks. These blocks are assembled on platen 20 (see Figure 5-34). The basic flow pattern of steel for flat blocks begins at the steel storage area, where steel plate and structural sections are held following delivery to the shipyard. Next, steel goes to the plate shop (location 907) for initial surface preparation and coating, followed by cutting of parts. These parts may then go directly through the panel line in the plate shop, or be palletized for subassembly on platen 23 or 24. The subassemblies built on platen 23 or 24, subassemblies from the panel line and other pallets of parts, are then moved to platen 20

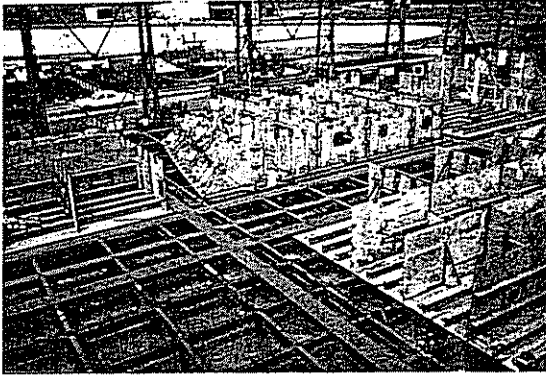


Fig 5-34(a)

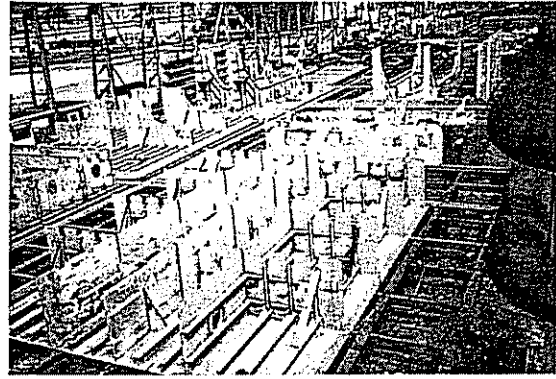


Fig 5-34(b)

Fig 5-34(a & b). Flat block platen (courtesy Avondale Shipyards).

for block assembly. Building 930, used for t-beam fabrication, and platen 15, a beam line subassembly location, also supply subassemblies for platen 20. Actual flow of these blocks on platen 20 includes stages for assembly upside down and right side up, and outfitting on-block. Following completion of the blocks on platen 20, they are moved to the blast and paint building to receive surface preparation and primer coating. These blocks are then moved to the area just outside the blast and paint building for additional on-block outfitting and then directly to the building position. Category (1) blocks are characterized by relatively high-volume, easy assembly work, accomplished with actual flow.

Curved shell blocks, category (2), are assembled on platen 17. This platen has pin jigs, and work on this process lane involves virtual flow. Parts are manufactured in the plate shop and subassembled on platen 16. An on-block outfitting stage is part of the platen 17 process lane. These blocks are then sent through the blast and paint facility and delivered to the building position. The work content and the amount of time curved blocks are in this process lane are both considerably greater than for flat blocks in platen 20.

Superstructure blocks, category (3), are assembled on platens 8, 9, and 11. These blocks

are large, flat blocks, outfitted primarily on-block. They are also commonly built in layers. Since they are in the process lane for long periods of time and are large and heavy upon completion, these blocks are assembled close to the building position. Subassemblies for these blocks are also built on platen 16.

Large, heavy, three-dimensional blocks, such as the fore peak and aft peak, are category (4) blocks and are built on platens 7, 10, and 13. Platen 16 supplies fabricated parts for these blocks, but only a small number of subassemblies are used, since these complicated blocks are primarily built piecemeal. These three platens are used due to large crane capacity and proximity to the building positions. This process lane is characterized by difficult, intricate work, requiring the most qualified mechanics.

Platen 14 is the location of the process lane for assembling engine room innerbot-toms, category (5). This location is in close proximity to the plate shop and panel line, and to platen 16, which provides fabricated parts and beam line subassemblies. Although these blocks are flat blocks, they are contained in a separate category and process lane because they are more complex, require closer tolerances, and have more outfitting than category (1) flat blocks. These blocks

will stay in the process lane longer than category (1) blocks and, like category (4) blocks, require the most qualified mechanics

The final block process lane, for category (6) blocks, is platen 19. These blocks include skegs, rudders, bilge keels, hatch coamings, bulwarks, and other special blocks. Fixed jigs are employed on platen 19 to aid in the assembly of category (6) blocks. Following completion, these blocks are transported to the blast and coat facility and then to the building position.

In addition to the block and steel subassembly process lanes, outfit material manufacture and installation are organized using outfit process lanes. Outfit parts are manufactured in shops, including the pipe shop, machine shop, sheet metal shop, and electric shop. Each of these shops is treated as a separate process lane for parts manufacture. These parts are then palletized for assembly on-unit, on-block, or on-board. On-unit outfitting takes place on platen 21, in the area adjacent to the pipe shop, or occasionally in one of the shops. These outfit units, assembled on one of these process lanes, are then moved to the area adjacent to the blast and paint facility for erection on-block, or to the building position for erection on-block or on-board.

This facility layout, although far from the optimal U shape of the proposed fourth-generation, group technology shipyard, indicates the approach existing shipyards must employ in adopting group technology. The details of the existing facility must be taken into account in reorganizing work locations. Comparatively little capital investment is required to alter an existing facility to adopt the process lane approach to shipbuilding.

3.2. Process Lane Loading

The goal of uniform work flow, either actual or virtual, throughout the shipyard should be sought at each workstation. Only mass pro-

duction manufacturing processes can be expected to completely achieve this goal. Consequently, process lane loading involves attempts to achieve uniform work flow in as much of the shipbuilding system as is possible. The practical approach to loading process lanes therefore entails the establishment of a hierarchy. This hierarchy is used to select process lanes to be level loaded on a priority basis. The hierarchy initially follows the hierarchy of the overall building process. Consequently, the erection process lane, i.e., the work at the building position, is the first process lane to be level loaded. The establishment of the master erection schedule is used to perform this level loading. This schedule will be discussed in detail in Chapter VII.

The next process lanes to be loaded are at the block assembly level. Here, shipyard-specific information must be used to establish priorities within this manufacturing level. In the example described above, flat blocks or category (1) blocks were chosen as the top priority for level loading. These are the most numerous and most easily built blocks. Consequently, level loading this process lane, platen 20 in the example, is a high priority in order to achieve a high degree of level loading throughout the shipyard. Process lanes that support platen 20 also receive considerable attention in order to provide uniform work flows.

The second process lane priority for level loading is for category (2) blocks, platen 17. The concept is to first load platen 20 uniformly at or near capacity. Next platen 17 is loaded as uniformly and as close to capacity as possible. The process then continues to lower-priority process lanes, attempting to provide the maximum overall uniformity of work levels, subject to not disturbing uniformity achieved at higher-priority process lanes. Work loading proceeds down the hierarchy, both at the block assembly manufacturing level and at lower (subassembly, outfit unit, and parts fabrication) manufacturing

levels. The loading of process lanes is continuously changing, responding to actual work progress, disruption, rework requirements, the incorporation of new work, and any other factors that affect the flow of work.

The establishment of workstation productivity indices is essential for the planning, scheduling, and control of work loads at process lanes. Productivity indices will be discussed in more detail in Chapter VII. Addi-

tionally, design and engineering must respond to work load leveling requirements. For example, if platen 20 is underutilized at a particular time, blocks may be designed or block breakdowns altered to permit their construction as flat blocks. Coordinating planning, scheduling, design, and material control to achieve uniform loading of process lanes is a key to successful group technology shipbuilding.

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SHIP DESIGN AND ENGINEERING

1. Introduction

Preceding chapters have discussed the theory of shipbuilding based on the application of group technology in shipyards. Application of these principles requires an alteration in the ship design and engineering process. This chapter will provide a description of the design and engineering process associated with group technology shipbuilding, rather than the specifics of ship design, which are adequately covered in other texts. Information will also be provided concerning techniques not commonly applied in traditional ship design that have applications for shipyards employing group technology. Finally, design and engineering for production is discussed.

1.1 Design Cycle

The outputs of the design cycle required by a group technology shipbuilder are different from those of conventional shipbuilders. Rather than a set of detailed plans suitable for use by any shipyard, the group technology shipbuilder requires work instruction packages that provide specific information for construction organized by the problem areas defined for the individual shipyard. Additionally, the design cycle must permit timely identification of material and production requirements to enable the shipyard to proceed with procurement, planning, and scheduling

consistent with the management and build strategy of the yard. Figure 3-2 (Chapter III) shows the management cycle undergoing transitions from system to zone and back to system orientation. Design and engineering follow a similar pattern. The stages of design and engineering, while similar to the traditional stages of concept, preliminary, contract, and detail design, produce considerably different outputs. The design stages employed by shipyards using group technology can be categorized as basic design, functional design, transition design, and work instruction design (see Figure 6-1). [1]

The design process, as it was commonly practiced in the United States, involved the use of design agents not specifically associated with the shipyard. [2] The design agents, rather than a shipyard-centered design and engineering group, performed most of the work prior to detail design, and in many cases including detail design. The adoption of the principles of group technology requires a different approach to this design process. It also necessitates much closer coordination between the designer (whether an outside design agent or a shipyard design organization) and the other departments within the shipyard, including production, material control, purchasing, and planning and scheduling. Significant differences from conventional design are the

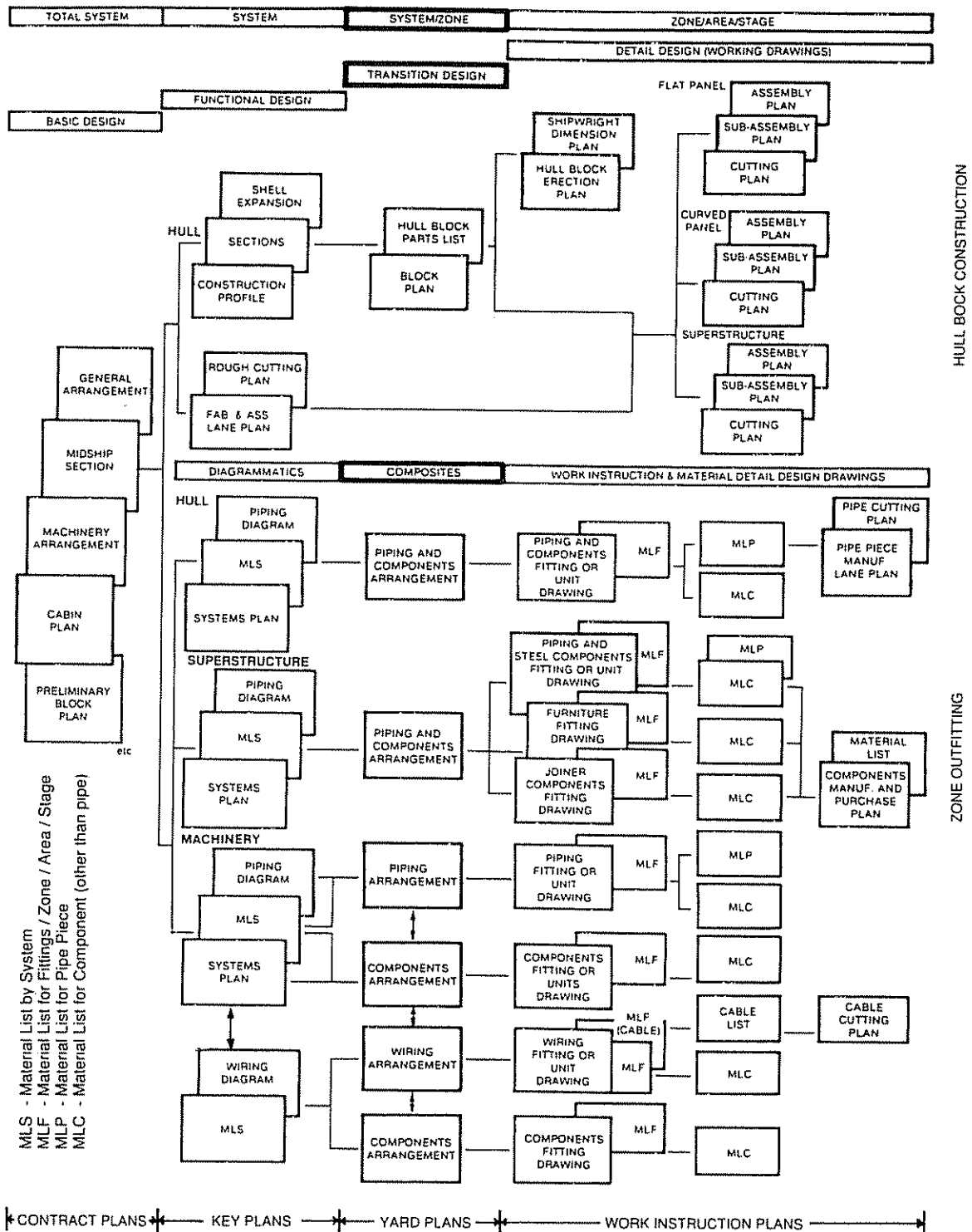


Fig 6-1. Product-oriented design process.

use of a shipyard-specific build strategy (developed before design begins), much earlier identification of material, the elimination of many expensive and time-consuming system arrangement drawings, identification of outfit work packages by product aspects on composite drawings; other differences occur in the terminology used and the organization of design stages. The four stages of design, shown in Figure 6-1, are described as follows:

- *Basic Design* describes a ship as a total system. It is sometimes based on an owner-sponsored preliminary design which generally fixes what the ship is to be and how it is to perform. Depending on complexity and the shipyard's experience with the owner, the end products are specifications and contract plans which may be limited to only a general arrangement and midship section or may be relatively extensive and detailed.
- *Functional Design* addresses each system in quasi-arranged diagrams for piping and wiring and in system plans, such as for a mooring system. Such documents are sufficient for owner and regulatory approvals and are called key plans. A material list by system (MLS) is prepared for each diagrammatic and system drawing.
- *Transition Design* regroups information organized by systems so as to organize the same information by zones. This first interrelationship of systems and zones, expressed on yard plans, is needed to guide the development of specific work instructions.
- *Work Instruction Design* groups design information by the additional product aspects, problem area, and stage, which are classifications of the manufacturing processes. This applies to both fitting work instructions for assembly work and manufacturing work instructions

for pipe pieces and other components. In sophisticated organizations, work instruction design is regarded as an extension of transition design, and end products are regarded as yard plans. Elsewhere, it may be helpful to maintain a separate identity of work instruction design and to call the end products work instruction plans. A material list for fittings (MLF) is prepared for each fitting work instruction. A material list for manufacturing a pipe piece (MLP) or a material list for manufacturing a component other than pipe (MLC) accompanies each manufacturing work instruction.

Figure 6-1 indicates some of the specific outputs of each stage of the design/engineering cycle. Note that as early as functional design, while still maintaining system orientation, the breakdown of work by problem area has taken place. This breakdown is first into hull block construction and zone outfitting and then, within zone outfitting, into hull, machinery, and superstructure. For naval ship construction, the additional problem area classification of combat systems could be employed.

1.2. Information Flow

During basic design and throughout the remaining design stages, production engineers from the hull construction department exchange information with the hull structural design group about matters such as block definition, the hull construction production plan, and yard plan need dates. While this is going on, outfitting production engineers work with outfit designers to define pallets, plan outfitting production, and establish pallet need dates.

The pallet concept is the basis for the control of work. Pallets can be viewed as empty buckets, which are to be filled by various hardware and software items (see Figure 6-2) [3]. Each pallet must contain informa-

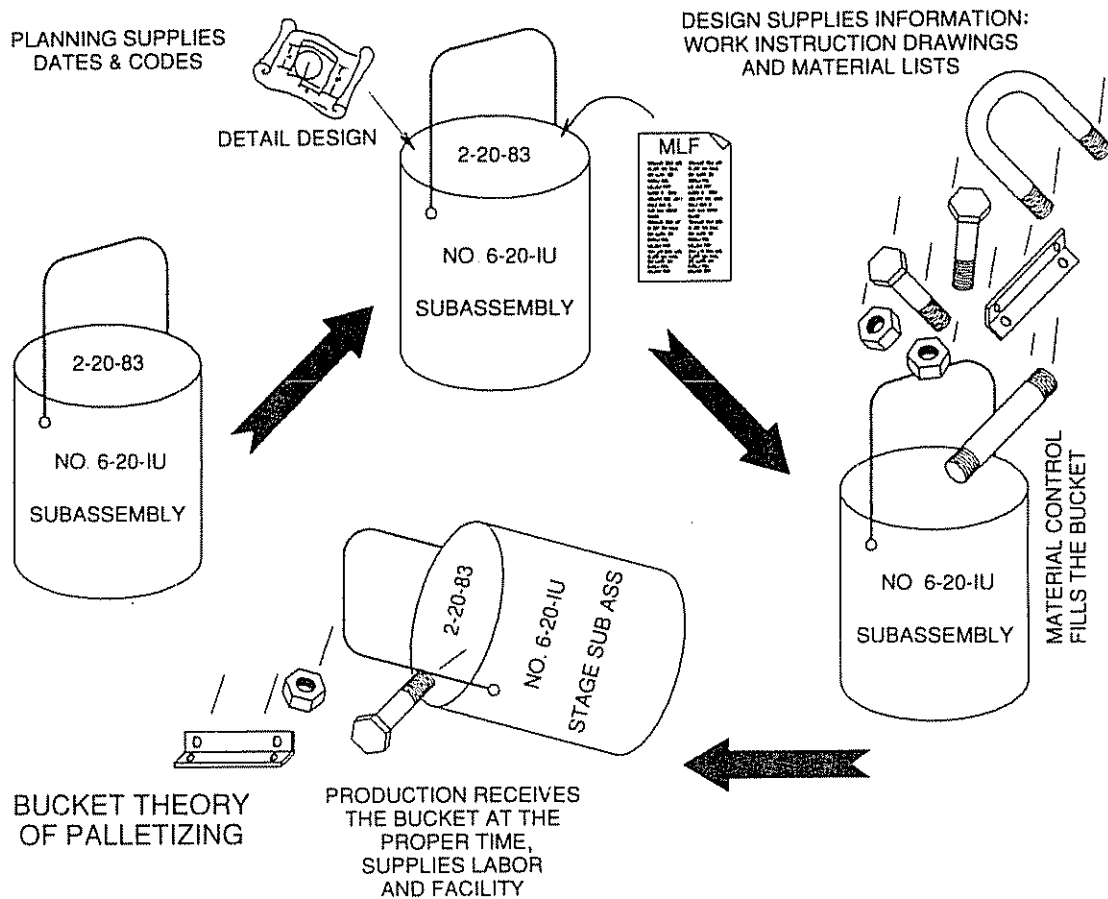


Fig 6-2. The pallet concept

tion, including work instructions, schedules, work locations, and material lists, and resources, including materials, tools, facilities, and manpower. Each pallet is defined (the empty bucket is identified), filled with the necessary information and resources, and delivered to the proper work site at the proper time. The work is then performed and the resulting interim product produced. Pallets therefore represent work packages that are identified by zone/problem area/stage and provide production with all the information and resources needed for executing a unit of work. Various pallet coding systems have been developed to facilitate the use of the pallet concept by design, material control, and production.

Simultaneously with pallet definition and design scheduling, outfit designers advise the hull structural group of outfit requirements for penetrations and reinforcements in structure. Similarly, outfit production engineers communicate with hull construction production engineers concerning requirements for outfitting on-block and on-board. Meanwhile, outfit designers define outfit components and raw material requirements as production engineers determine need dates by pallet. These are conveyed to procurement people by requisitions in advance of the lead times provided by the procurement people. Typical information paths for this interchange of information necessary for integrated hull construction, outfitting, and painting are illustrated

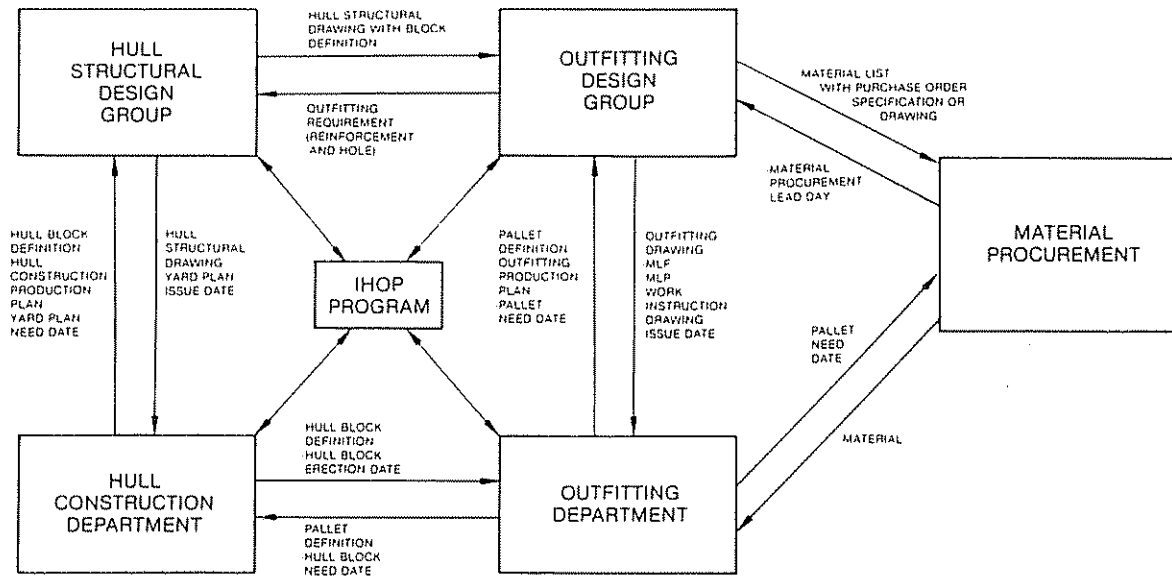


Fig 6-3 Information interchange to integrate HBCM, ZOFM, and ZPTM

in Figure 6-3. Throughout, pallets serve as essential communication links.

1.3 GT Shipbuilding Impact on Design/Engineering

In addition to the altered design cycle and the differences between GT shipbuilding design and conventional design described earlier, other major characteristics of group technology design are:

- work instruction design (formerly detail design) organized by zone, problem area, and stage instead of by system
- greater detail required
- design and engineering completed earlier
- material definition completed much earlier
- greater coordination with production required
- design and assembly details standardized

Additional information must be provided as a part of the work of the engineering department.

Also, the design must take into consideration additional factors. These include:

- assembly sequences
- welding sequences
- tolerances, excess, and edge preparation by stage
- coating requirements by stage
- subassembly, unit, and block interfaces
- tools of production
- work sites
- structural integrity of subassemblies, units, and blocks upright and upside down
- support and pick points for moving and turning subassemblies, units, and blocks
- minimization of distortion of subassemblies, units, and blocks during moving and turning

Some of this information may have been provided by other shipyard groups, such as the mold loft, planning, or production, but greater detail and better documentation than has been common practice is required.

Table 6-1. Comparison of intensity of engineering effort for a large commercial vessel construction project

	Conventional Construction	Group Technology Construction
Total Engineering Man-hours	350,000	500,000
Percent Complete at Construction Startup	60	80
Months from Contract to Construction Startup	14	12
Man-hours per Month Prior to Construction Startup	15,000	33,000

The overall result of these requirements is an intensification of the engineering effort. Table 6-1 summarizes this effect for a typical large commercial vessel construction project. [3] As can be seen in this table, the intensity of the engineering effort more than doubles with the application of group technology shipbuilding methods. Figure 6-4 further am-

plifies this. The figure shows the percentage of the engineering effort that must be completed as a function of time after the contract is signed. The start of the engineering process must be coordinated in order to permit the higher intensity of effort to be effective. Means of achieving this goal will be discussed in conjunction with basic design.

2. Design Stages

As previously described, the shipbuilding design cycle can be subdivided into four stages: basic design, functional design, transition design, and work instruction design. Each of these design stages is directly related to stages of the shipbuilding process. In describing the four design stages, the achievement of specific, predetermined milestones related to each must be kept in mind. Figure 6-5 shows a breakdown of the complete design cycle, indicating milestones to be achieved at the end of each stage. The use of formal meetings with set agendas at the conclusion of design stages can be a means of verifying progress and communicating the results not only within the design group but also to all affected shipyard organizations

2.1. Basic Design

Contract plans are produced during the basic design stage. These plans provide a general

overview of the ship to be built and consequently represent a total ship system orientation. Among the plans developed as part of basic design are:

- general arrangement
- lines
- midship section
- machinery arrangement
- cabin plans
- diagrammatics of major outfit systems
- electric one line diagram
- contract specifications

As a part of the basic design process, normal naval architectural calculations are performed. Among these are:

- weight estimate
- longitudinal strength
- hydrostatics

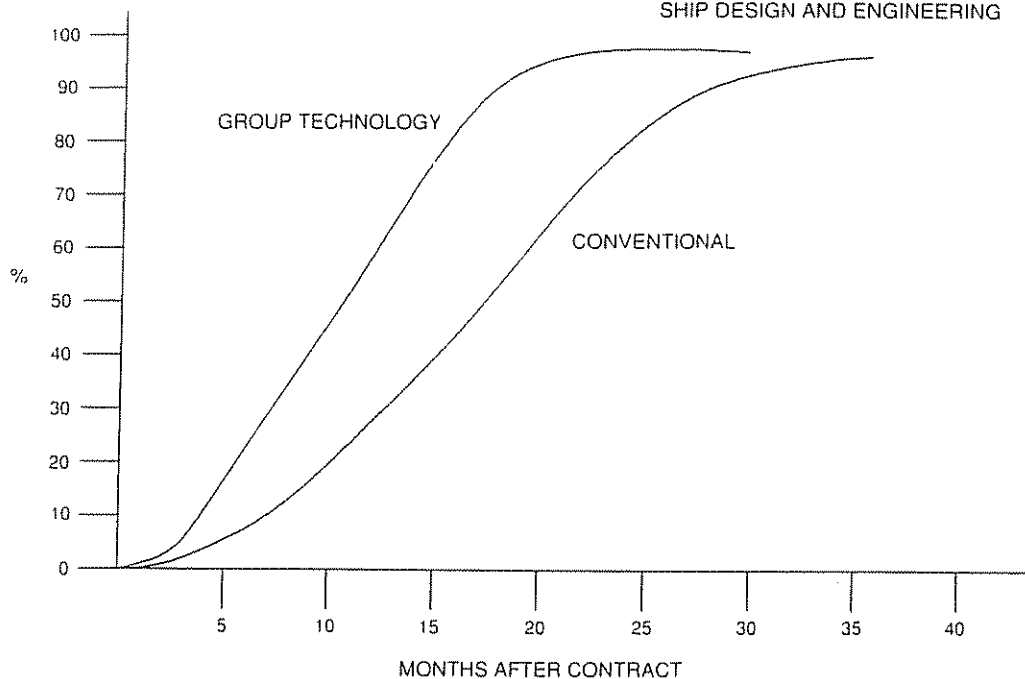


Fig 6-4. Intensity of group technology engineering effort

- tank capacities
- Bonjean curves
- intact trim and stability data
- loading conditions
- damaged stability evaluation
- wake survey
- resistance and self-propelled tests
- electric load analysis
- HVAC analysis
- piping systems analysis
- propeller design
- shafting arrangement

Development of a first refinement of the generic build strategy is also considered during basic design. This involves preliminary determination of the block plan (see Figure 6-6), the breakdown of outfitting on-unit, on-block, and on-board, the identification of material purchasing zones, and the preliminary determination of the outfit pallet list. An original or preliminary budget control list is also developed. This list is an estimate of all material needs by total weight by material family or cost code and draws heavily on shipyard experience. The development of a

build strategy will be discussed in detail in Chapter VII.

In a preliminary manner basic design needs to:

- define simple, logical block boundaries
- define blocks of maximum size and weight permitted by the shipyard's assembly and erection processes and facilities
- minimize the number of blocks, if necessary by joining blocks which are sized to facilitate assembly into grand blocks, in order to exploit a large-capacity crane at an erection site
- identify assembly and erection processes consistent with safety and the need for block accuracy and rigidity
- minimize scaffolding, lifting, turn-overs, etc.
- identify blocks which can be used as patterns for other blocks in parallel midbody
- identify preliminary zone, problem area, and stage classifications for organizing work flows and, as much

as possible, equalizing the contents of work packages for block assembly, subassembly, and parts fabrication

Besides this, block predefinition should consider how to:

- install machinery and fit other components in the engine room
- arrange deck machinery, mooring fittings, etc.
- perform as much painting as possible before hull erection

Assessment of the efficiency of block assembly processes in terms of durations, numbers of required resources, accuracy needed, and quality of work circumstances also requires the following to be evaluated collectively:

- determinations of outfitting on-block or on-grand block
- ease of outfitting and painting processes
- avoidance of damage to painted surfaces and to fittings when turning over or otherwise handling blocks

Basic design is concerned with the development of procurement specifications for long-lead-time and other important outfit components. These may include:

- main propulsion engines
- diesel generators
- ballast pumps
- waste heat boiler
- anchor windlass
- mooring winches
- dehumidification units
- lube oil, fuel oil, and diesel oil purifiers
- plate heat exchangers
- engine room console
- cargo system console
- electric motors

Fig. 6-5(a) The design and engineering cycle, marketing to contract.

ENGINEERING PROCEDURE AT ASI

MARKETING STAGE DEFINITIONS

- (A) - CONTRACT SPECIFICATION
- SHIP PROPORTIONS
- DRAWINGS

LINES

- GENERAL ARRANGEMENT OF HULL AND MACHINERY
- SUPERSTRUCTURE AND QUARTERS ARRANGEMENTS
- MIDSHIP SECTION
- SCANTLING SECTIONS
- PRELIMINARY SHELL EXPANSION
- CARGO OIL SYSTEM DIAGRAM (3)
- INERT GAS, DEHUMIDIFICATION AND CARGO VENT DIAGRAMS (3)
- 43 TANKS
- ENGINE - RELATED AND OTHER PIPING DIAGRAMS
- DIAG. MAIN ENGINE LUBE OIL SYSTEM
- DIAG. MAIN ENGINE CYLINDER LUBE OIL SYSTEM
- DIAG. LUBE OIL FILLINGS, TRANSFER AND PURIFIER SYSTEM
- DIAG. STERN TUBE LUBE OIL SYSTEM
- PIPING MATERIAL SCHEDULE
- DIAG. ENGINE ROOM BILGE & BALLAST SYSTEM
- DIAG. SEGREGATED BALLAST SYSTEM
- DIAG. FEED AND CONDENSATE SYSTEM
- DIAG. FIREMAIN - ENGINE ROOM
- DIAG. FIREMAIN - ACCOMMODATIONS
- DIAG. FIREMAIN AND FOAM SYSTEM - MAIN DECK
- DIAG. CENTRAL FRESH WATER COOLING SYSTEM
- DIAG. MAIN ENGINE JACKET WATER COOLING SYSTEM
- DIAG. MAIN ENGINE PISTON COOLING WATER SYSTEM
- DIAG. MAIN ENGINE FUEL VALVE COOLING WATER SYSTEM
- DIAG. MAIN SEA WATER COOLING SYSTEM
- DIAG. AUXILIARY SEA WATER COOLING SYSTEM
- DIAG. VENTS, SOUNDING TUBES AND OVERFLOWS
- DIAG. STEAM SYSTEM
- DIAG. SHIP'S SERVICE, STARTING AND CONTROL AIR SYSTEM
- DIAG. FUEL OIL SERVICE SYSTEM
- DIAG. FUEL OIL FILLING, TRANSFER AND PURIFICATION SYSTEM
- DIAG. DIESEL OIL SYSTEM
- DIAG. FUEL SLUDGE AND MAIN ENGINE CLEANING SYSTEMS
- DIAG. TANK HEATING COILS

- CALCULATION OR OTHER TECHNICAL DATA

- WEIGHT ESTIMATE
- LONGITUDINAL STRENGTH
- HYDROSTATICS
- TANK CAPACITIES
- BONJEANS CURVES
- INTACT TRIM AND STABILITY DATA
- LOADING CONDITIONS
- DAMAGED STABILITY EVALUATION
- WAKE SURVEY
- RESISTANCE AND SELF PROPELLED TESTS
- ELECTRIC LOAD ANALYSIS
- ELECTRIC ONE LINE DIAGRAM
- VENT SYSTEM DEVELOPMENT AND DUCT OPENING

- PROCUREMENT SPECIFICATIONS

- MAIN PROPULSION ENGINES
- DIESEL GENERATORS
- CARGO OIL PUMPS
- BALLAST PUMPS
- WASTE HEAT BOILER
- ANCHOR WINDLASS
- MOORING WINCHES
- INERT GAS SYSTEM
- DEHUMIDIFICATION UNITS
- LUBE OIL, FUEL OIL, AND DIESEL OIL PURIFIERS
- PLATE HEAT EXCHANGERS
- ENGINE ROOM CONSOLE
- CARGO SYSTEM CONSOLE
- ELECTRIC MOTORS FOR CARGO PUMP
- BOW THRUSTER
- STEERING GEAR
- BLENDING UNIT
- AUXILIARY OIL FIRED BOILER
- FUEL OIL PUMP / HEATER SETS

- OTHER REQUIRED DATA

- / INITIAL REGULATORY BODY REVIEW
- / PRELIMINARY UNIT DEFINITION
- / IDENTIFICATION OF CONSTRUCTION METHOD
- / ESTABLISH OUTFITTING ZONES FOR PURCHASING
- / STUDY AND PRELIMINARY ASSIGN PACKAGE UNITS ON BOARD AND ON UNIT MATERIAL

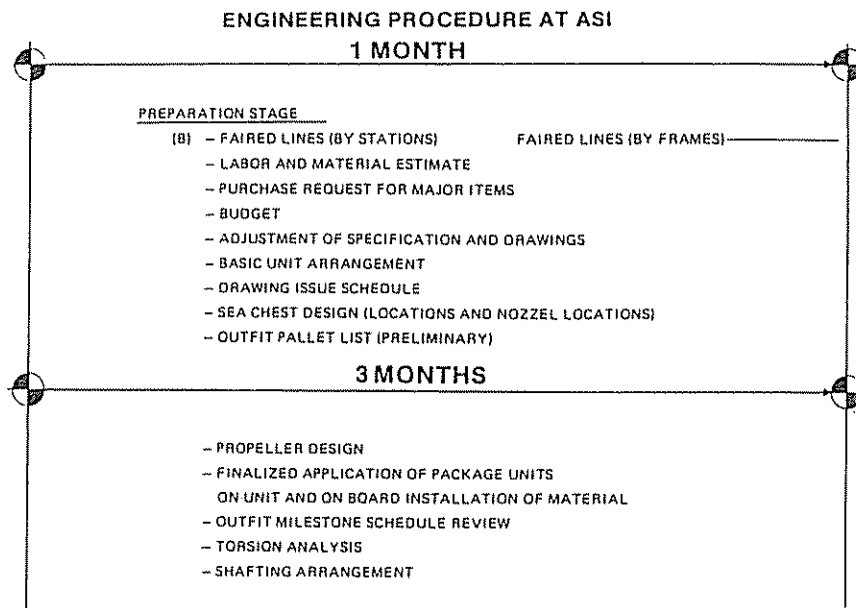


Fig 6-5(b) The design and engineering cycle, contract to Go meeting

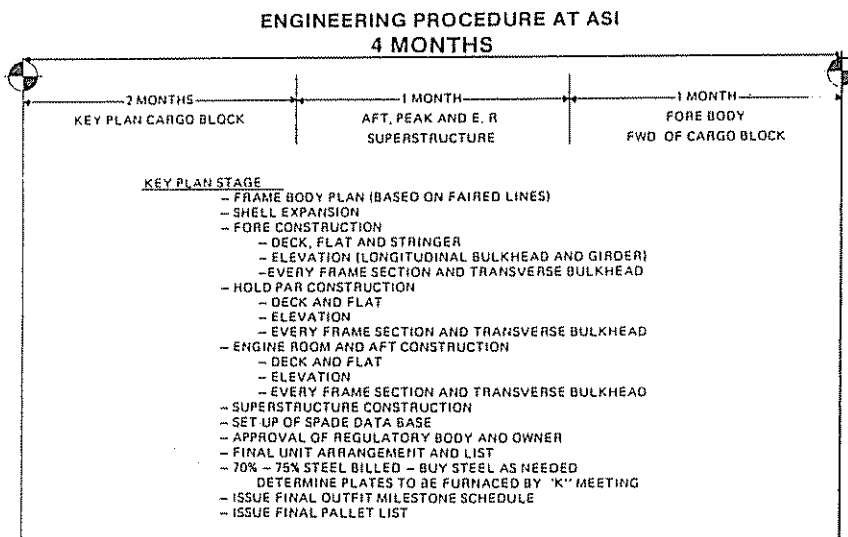


Fig 6-5(c) The design and engineering cycle, Go meeting to K meeting

- bow thruster
- steering gear
- auxiliary oil-fired boiler
- fuel oil pump/heater sets

Finally, basic design should enable preliminary regulatory body reviews to begin.

In some cases, part of basic design can be completed prior to contract signing. It should

draw heavily on existing shipyard standards and techniques in building similar vessels, similar outfit systems, and similar blocks (such as double bottoms, engine rooms, and superstructure).

2.2. Functional Design

Functional design, like basic design, is system oriented. Key plans are the output of this

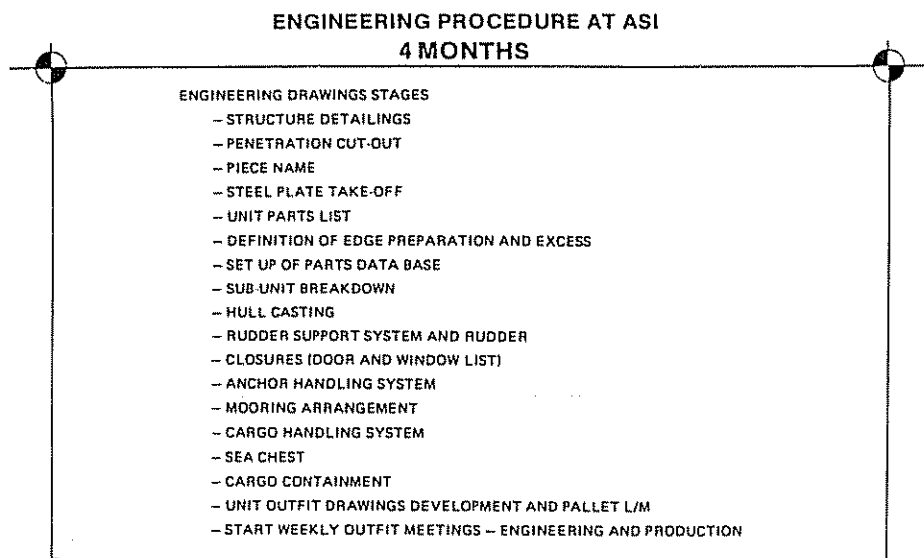


Fig 6-5(d). The design and engineering cycle, K meeting to ML meeting

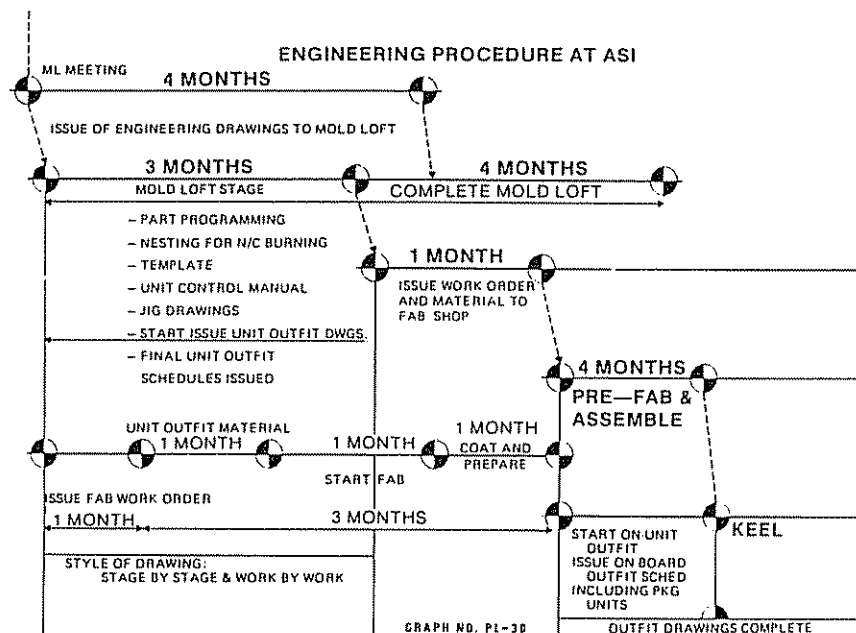


Fig 6-5(e). The design and engineering cycle, ML meeting to keel laying

stage. The objectives to be achieved during the functional design stage, as shown in Figure 6-7, include:

- display of all ship's functions on system diagrammatics and plans
- definition of all outfit materials required by system, including raw

materials (such as pipe, structural angle iron, and electric cable)

- issue the first revision of the budget control list, which advises all concerned of updated material quantities and weights
- prepare purchase specifications not prepared by basic designers

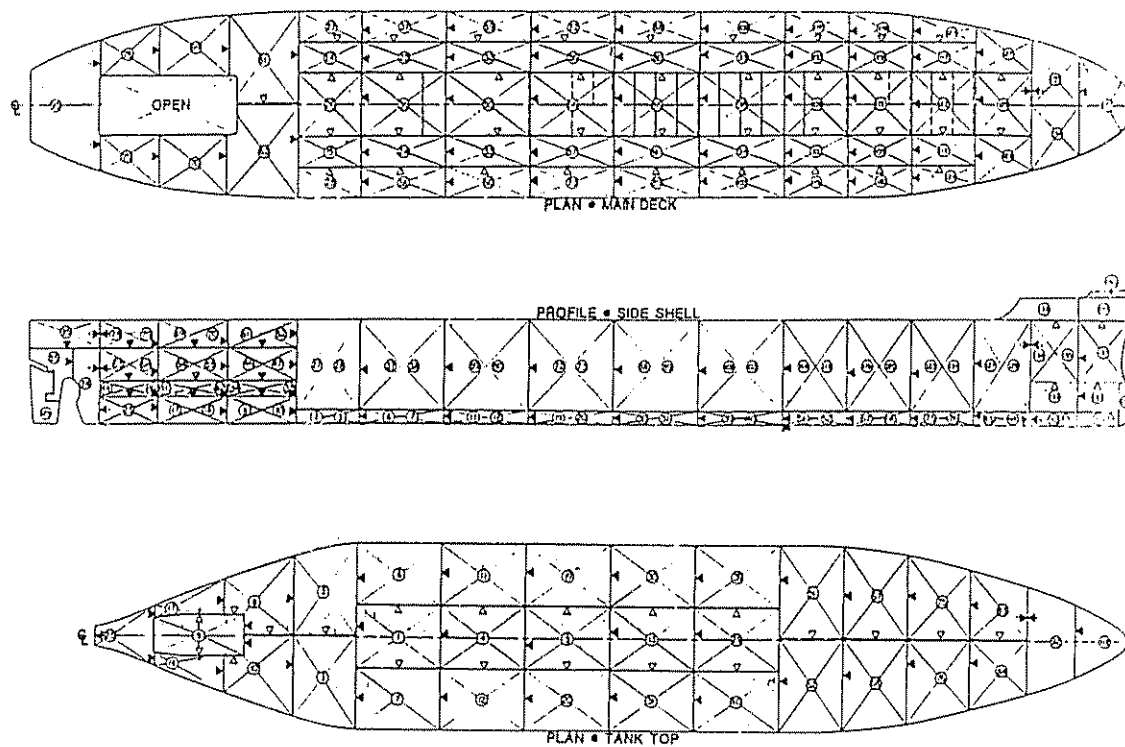


Fig 6-6 Preliminary block plan

- prepare manufacturing drawings for long-lead-time items identified during functional design
- obtain owner and regulatory approvals
- approve vendors' drawings

The information developed during basic design is refined during functional design, and the amount of detail is greatly expanded. The initial key plans developed include:

- hull scantlings
- block weight (approximate) and preliminary block arrangement
- midship section and typical transverse bulkhead
- stern frame and rudder
- main engine and equipment foundations
- welding plan
- machinery arrangement
- piping diagram
- purchase order specifications (main machinery)
- MLS (long-lead-time delivery items)

As functional design continues, the following key plans are drawn:

- frame body plan (based on faired lines)
- shell expansion
- fore body construction
 - decks, flats, and stringers
 - elevations (longitudinal bulkheads and girders)
 - frame sections and transverse bulkheads
- mid body construction
 - decks and flats
 - elevations
 - frame sections and transverse bulkheads
- engine room and aft body construction
 - decks and flats

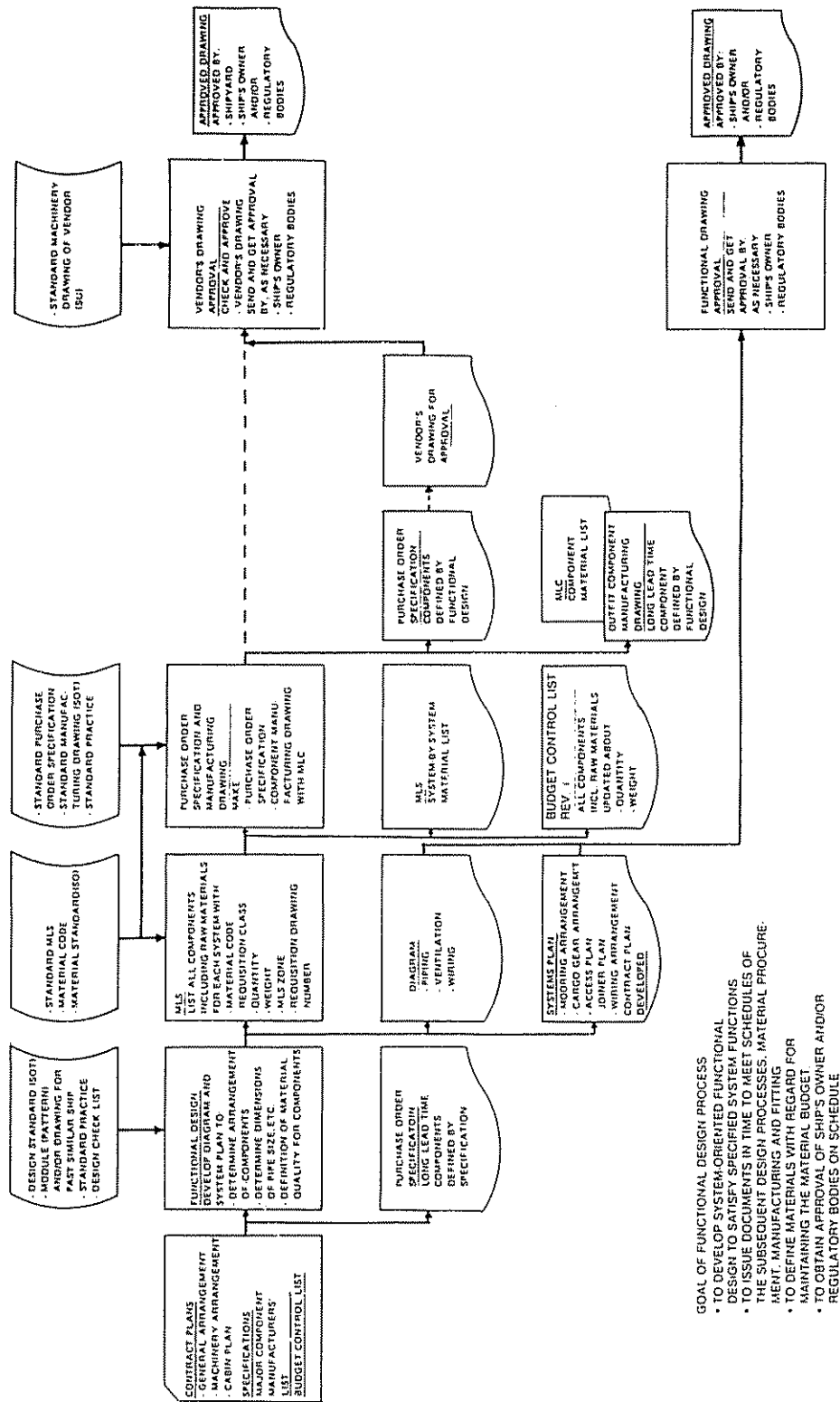


Fig. 6-7. Functional design responsibilities.

- elevations
- frame sections and transverse bulkheads
- superstructure construction
- setup of mold loft data base
- approval of regulatory body and owner
- final block arrangement and list
- 75 percent steel billed—buy steel as needed
- final outfit milestone schedule
- final pallet list

Additionally, detailed naval architectural calculations are performed during functional design. These include:

- calculation of midship structure
- calculation of transverse strength of shell plate
- calculation of buckling strength of shell plate
- calculation of strength of transverse and longitudinal bulkheads
- calculation of plating sheer diagrams
- calculation of local vibrations
- calculation of scantlings beyond midship area
- calculation of steel weight of the hull
- calculation for main foundations

2.2.1 System Diagrammatics and Key Plans

An immediate concern during preparation of key plans is to optimize ship's functions consistent with regard for operational and maintenance aspects. Typical structural key plans are shown as Figures 6-8, 6-9, 6-10, and 6-11. Typical diagrammatic and system plans are shown in Figures 6-12 and 6-13, respectively.

Each diagrammatic shows subdivisions, except for electrical systems, to the extent that it was prepared by more than one of the outfit specialty groups (hull, machinery, and superstructure). It is further subdivided, including electrical systems, by each outfit specialty group into a few material-ordering zones (see Figure 6-14). These reflect the erection sequence, so that purchasing and

manufacturing orders for long-lead-time materials can be placed before completion of the remaining design stages. Distributive systems, such as piping, ventilation ducts, walkways, and electric cable, are sized on system plans. The operational aspects of each system are then balanced, locations are shown for fittings whose exact positions are to be owner and/or regulator approved, and general system instructions are incorporated.

Other than the subdivision of diagrammatics by outfit specialty and by material-ordering zones, and locating fittings requiring owner or regulator approval, functional designers defer locating fittings to a later design stage. After system diagrammatics and system plans are revised commensurate with owner and regulator approval comments, they are key inputs for guiding the next design stage.

2.2.2 Material List by System (MLS). Tabulating all required material by MLS for each key plan is a major functional design responsibility. Purchased components, fittings to be manufactured in-house or outside, and raw materials are included in the following manner:

- items which can be identified and counted are listed by full descriptions and exact quantities
- items which can be identified but not counted are listed by full descriptions and estimated quantities
- remaining items are listed by total estimated weight by cost code

Special effort is applied to finalize the definition of all long-lead-time materials on MLS by the first or second method noted. The definition of short-lead-time materials can remain by total estimated weight by cost code until a subsequent design stage. However identified, short-lead-time materials are needed in MLS because MLSs are the basis for updating the budget control list. Thus, the purposes of MLS are to issue the first revision to material quantities on the budget control list

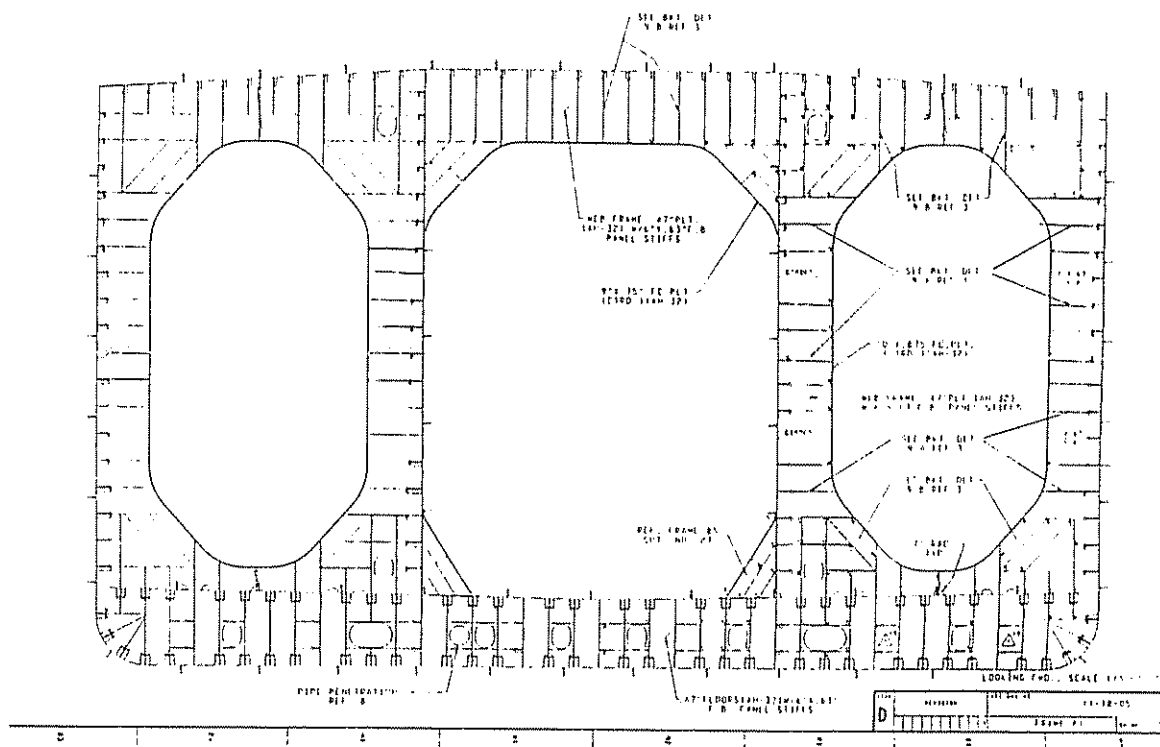
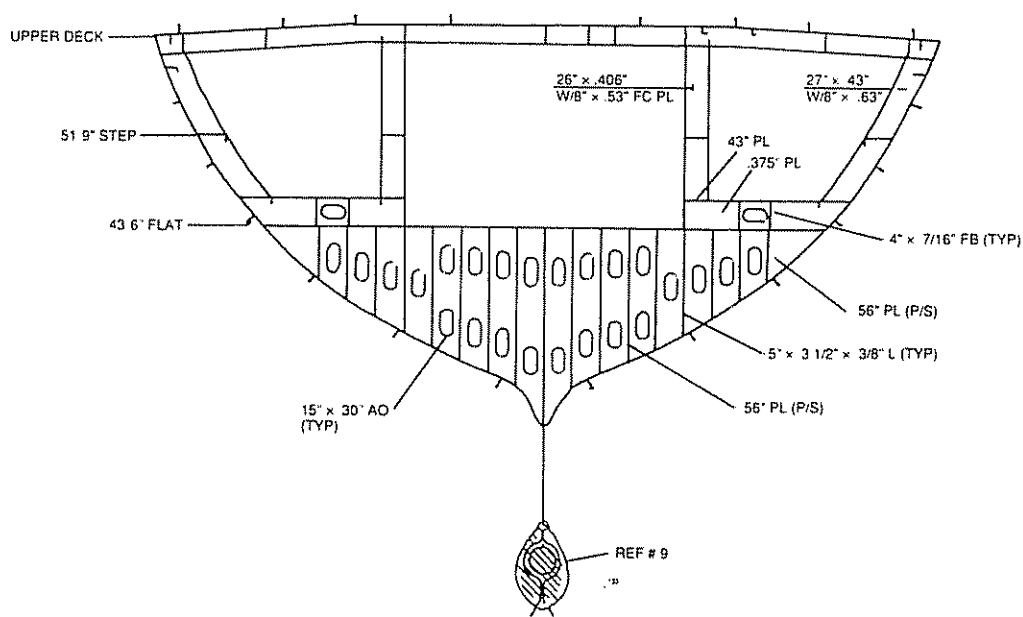


Fig. 6-8 Structural key plan



DETAIL 66-A

TRANSV WEB FR 10 LKG FWD

SCALE 1/4" = 1' 0"

Fig. 6-9. Structural key plan.

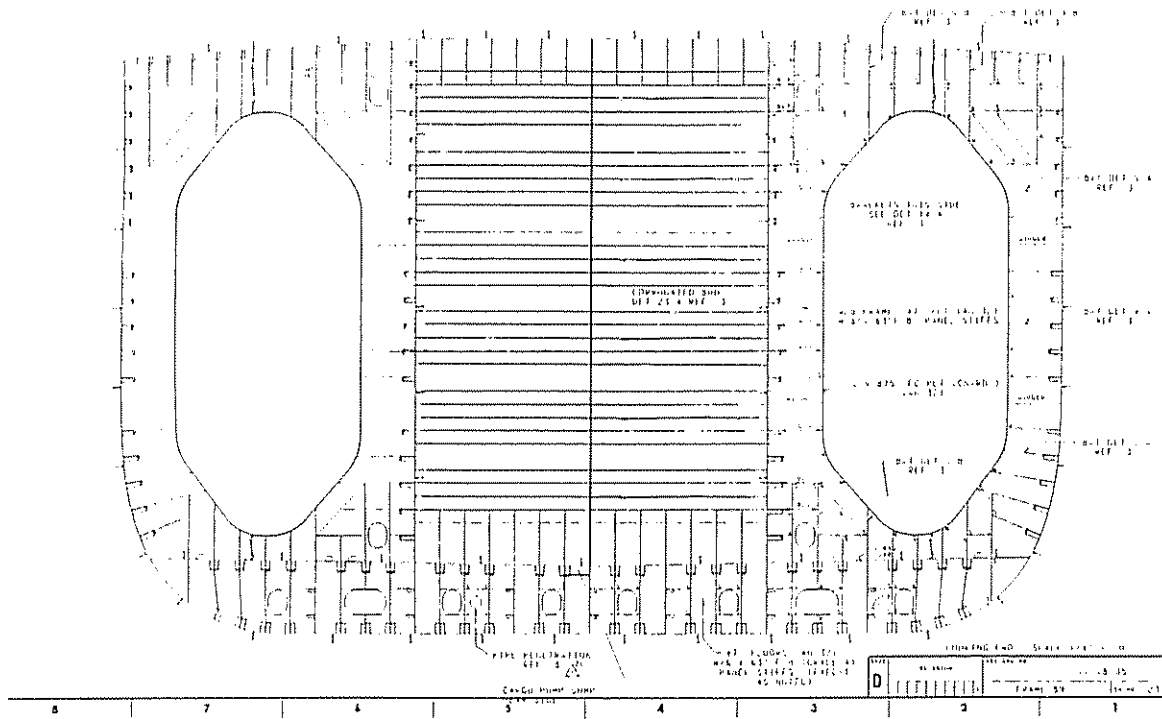


Fig 6-10 Structural key plan.

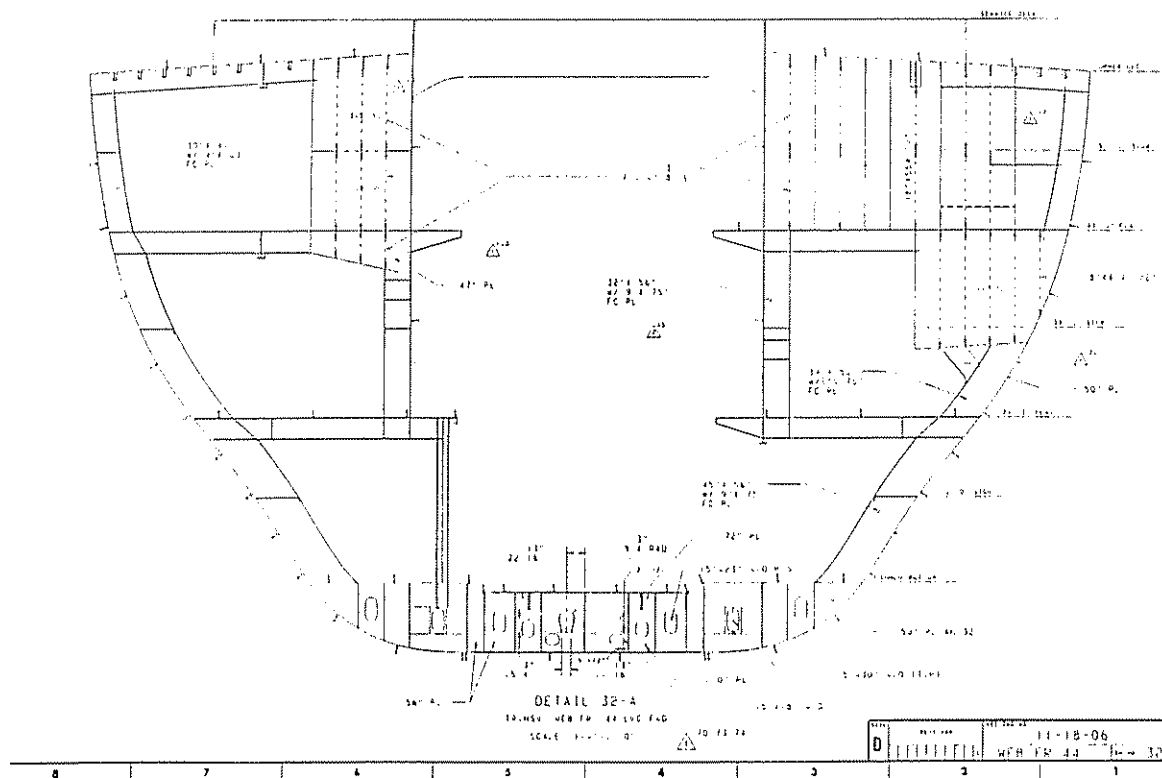


Fig 6-11 Structural key plan

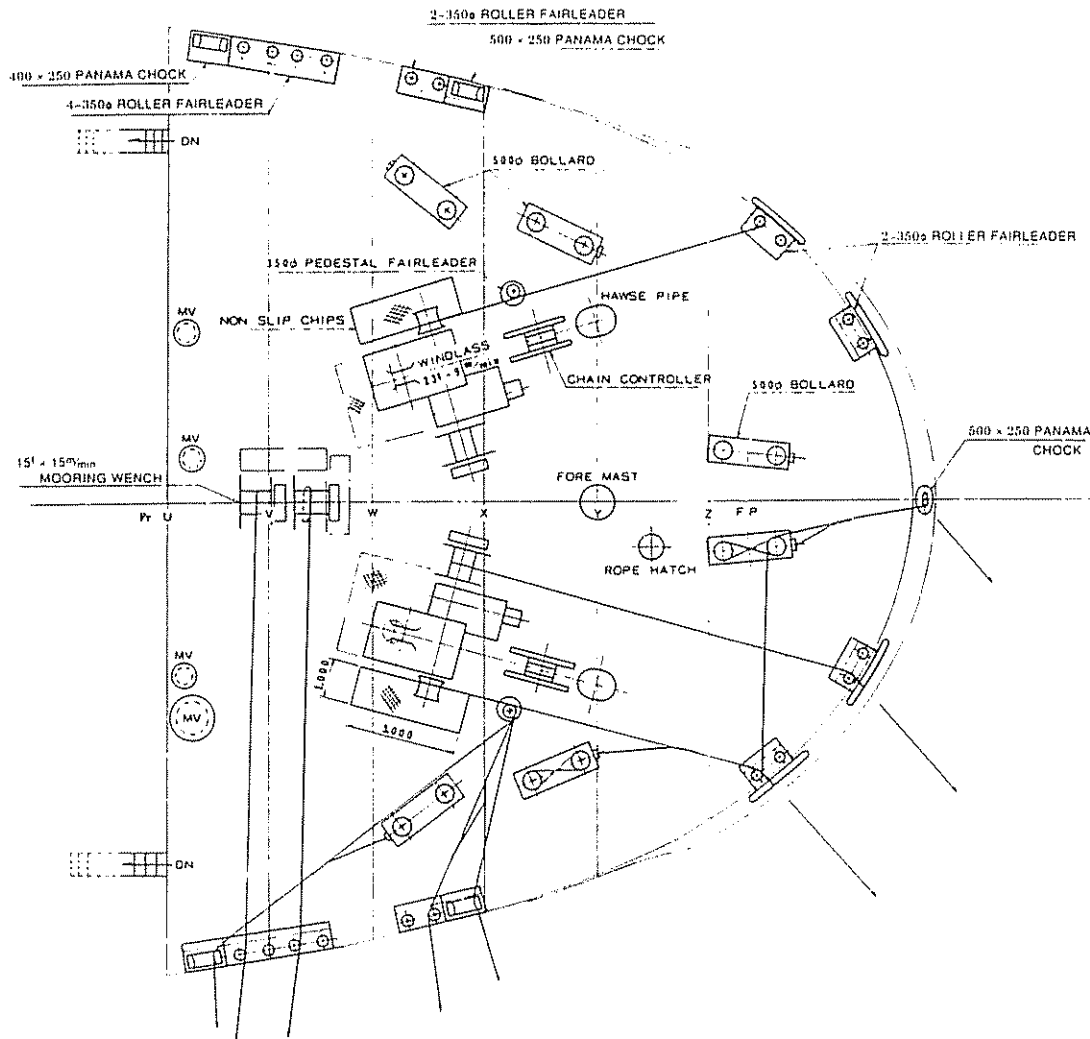


Fig 6-13 System plan for part of forecastle deck mooring system.

to improve control of material and man-hour costs and to begin the major outfit material procurement effort as early as possible.

MLSs are delivered to the material control department, where they are screened to identify common and long-lead-time materials, sequenced in accordance with dates assigned by material-ordering zones, and checked against the shipyard's inventory. Immediately thereafter, the material-requisitioning process is begun.

Since MLSs initiate a massive procurement effort, functional designers must en-

sure that material descriptions include specifications and drawings as necessary for both in-house manufacture and outside procurement. Such descriptions are in accordance with material requisition and control classifications as well as material codes. The full description for each material item listed in MLS includes:

- material code
- piece number
- material cost classification number
- material listing classification

- parent/child sign, where an item to be manufactured is called a parent and the parts and raw materials are called children
- material requisition classification
- material control classification
- material purchasing classification
- weight
- quantity
- material-ordering zone

Concerning the parent/child sign, both are listed on MLS so they may be screened for common and long-lead-time materials by material controllers. The parent sign is needed for production, budget, and cost control as well as for procurement. The child sign is needed for procurement only. Figure 6-15 is an example of a material list by system (MLS).

Material definition imposes a significant workload on functional designers. Employ-

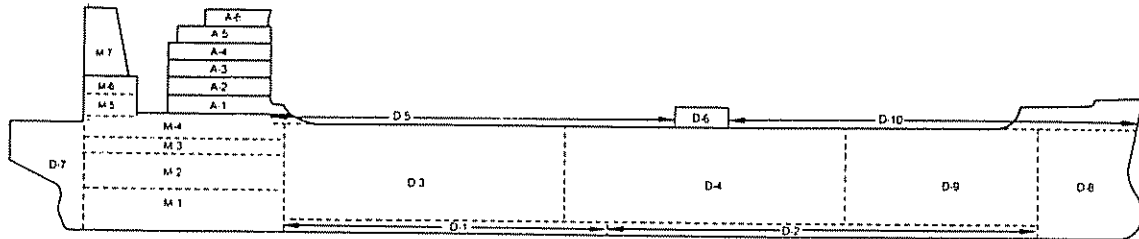


Fig 6-14 Material ordering zones.

DATE 2/17/81 LIST OF MATERIAL		QUANTITY (1) SHIP		P.O. NO. REQ NO. 6247F	
PC MK.	QTY	DESCRIPTION	UNIT PRICE	TOTAL PRICE	
000180809	10	BHD & DECK PENETRATIONS STEEL WT & OT ASI MECH STD NO 11 3 IPS			
000180876	43	SLEEVE STL WELDED SLIP ON TYPE ASI MECH STD NO 10 1 1/2			
000180877	33	SLEEVE STL WELDED SLIP ON TYPE ASI MECH STD NO 10 2			
000180879	42	SLEEVE STL WELDED SLIP-ON TYPE ASI MECH STD NO 10 3			
000180881	2	SLEEVE STL WELDED SLIP ON TYPE ASI MECH STD NO 10 4			
000181159	4	VENT ANTI SIPHONIC PVC BODY MONEL SCREEN MIN VACUUM TO VENT 1" WATER MIN PRESSURE TO SEAL 1" WATER 3/4 FPT			
000181612	21	DECK DRAIN STL SOCKET WELD TATE 60-160 W/BASS STRAINER GALV WITHOUT TRAP AND BAFFLE 2			
101000284	4	NUT STEEL GALV Hvy HEX MIL-B-857A 5 ASTM A307 ANSI B18.2.2 5/8 UNJC 2B			
101011109	4	BOLT STL GALV MM MIL-B-857A 5 TY 2 GR 2 ASTM A307 GR 8 5/8 UNJC 2A X 3			
OR	AVONDALE SHIPYARDS, INC P O BOX 50280 NEW ORLEANS, LA. 70150		CUSTOMER ODGEN MARINE INC		
CKD	TITLE		JOB NO. CB-0750		
APPD	PLUMBING & INT DK DRNS OTRS "C" DK & ABOVE LM		DWG NO 46 08 141		REV 2
CODE 0613	NO OF VESSELS 2		DATE 2/17/81		SHEET 8

Fig. 6-15 Material list by system (MLS)

ment of standard materials as much as possible is essential. If all parties concerned, including potential suppliers, maintain up-to-date files of standard material descriptions, material codes are sufficient for describing such materials on MLS. Thus, the effectiveness of functional designers is directly related to the effectiveness of a standards program.

A nonstandard item requires additional attention from the functional designer. These items can be manufactured in-house or outside in accordance with a shipyard drawing or they can be supplied by a vendor, based on the vendor's drawing. The former require functional designers to prepare a drawing and a material list for components (MLC). The latter require review of technical aspects of vendor proposals in response to specifications prepared by the functional designer. The material definition outputs of functional design, which are sent to the material control group for procurement, are MLS, shipyard drawings with MLC, and approved vendor drawings and specifications.

Functional designers must be very knowledgeable of the material definition system and must be aware of the need for just-in-time material procurement anticipating a zone-by-zone outfitting strategy. This means judicious sequencing of material definition to expedite the definition of long-lead-time and vendor-designed materials, while deferring definition of other material. Otherwise there can be no rapid start-up, which is extremely important. As numerous materials are required and various categories of information are necessary for each item, computer processing is essential.

2.3. Transition Design

Transition design is basically the process of transforming system-oriented information into zone-oriented information. The end products are yard plans, so named because they represent the first grouping of information to suit

the way production work is organized. Thus, yard plans must be based on a preconceived pallet list (outfitting strategy).

The flow of transition design responsibilities is shown in Figure 6-16. During transition design, work is by zone rather than by system. The yard plans are used to develop the actual procedures to be followed in building the ship, using the work instructions. Since production is controlled by the pallet concept, transition design is based on the establishment of a pallet list. Yard plans generally take the form of composites.

2.3.1 Pallet Definition. Pallet definition that facilitates integrated hull construction, outfitting, and painting (IHOP) is required for transition design. Thus, an early aspect of transition design is the creation and refining of a pallet list in terms of zone/problem area/stage. Coordination between hull structural designers and designers from the outfit specialty groups is essential. A meeting between representatives of these design groups plus planners and production engineers can facilitate this coordination. Inputs include predefinition for both blocks and pallets represented by hull construction and outfitting planning groups, respectively.

The hull construction and outfitting production plans are explained by the respective planning groups. Designers describe block weight, fitting positions, and material volume (weight and quantity) of outfit components, etc. As a consequence of such discussion, block definition may be adjusted. Thus, the outputs of this coordination are final block definition and an original pallet list.

With designers participating, decisions are made concerning:

- loading methods for major machinery, such as main engines, boilers, and generators
- fitting methods for auxiliary machinery and other components

- fitting stages, including on-unit, on-block (before and after turnover), and on-board
- size and weight limitations
- final block definition (positions of erection butts and seams)

Composite drafts show the first interrelationships of systems and zones. Therefore, further coordination, possibly in a second meeting, is required during transition design, just after diagrammatics are roughly arranged. Design and production engineers representing the outfitting specialties are again in-

involved. Decisions based on study of the composite drafts provide guidance to transition designers for preparing finished composite arrangements. Final agreement is obtained once the composite arrangements are completed. The production engineers are thus assured that the agreed-upon outfitting strategy is incorporated before the start of work instruction design.

2.3.2. Composite Drafts. During transition design, systems as defined on diagrammatics are roughly arranged as shown in Figure 6-17 in accordance with a furnished pallet list (out-

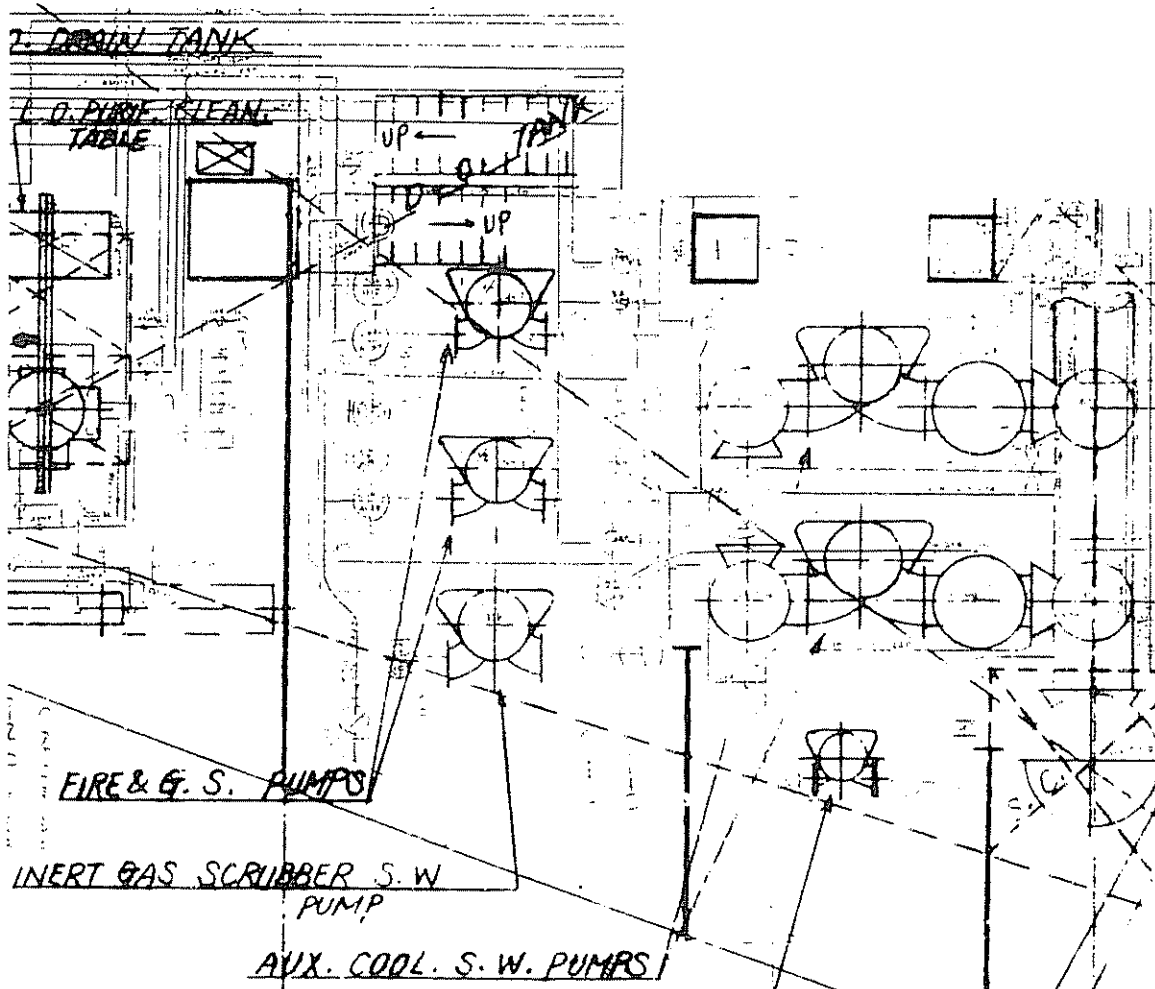


Fig 6-17 Composite draft of an engine room

fitting strategy). Only details affecting functional aspects and building aspects (such as locations of controls, valves, and gauges relative to a pump, or fittings relative to erection butts and seams), are specifically defined. Thus, the preparation of yard plans is assigned to the most experienced individuals having good command of both ship-operating and shipbuilding methods.

Each composite draft incorporates a number of contiguous pallets so that a well-balanced fittings arrangement can be achieved for a relatively large region by a few designers. For example, an attempt is made to distribute engine room systems equally to port and starboard as well as equally on the tank top and various engine room flats.

The rough composites, rather quickly produced, are nonetheless arrangement requirements that less experienced designers must follow for preparing relatively finished versions, i.e., composite arrangements. Also, composite drafts provide the needed interfaces which permit the more laborious preparation of composite arrangements to be readily apportioned by zone to more people than could be otherwise employed. This may include people in outfit specialty shops or in independent design firms.

Composite drafts are usually produced for congested arrangements, as in an engine room. For less difficult regions, the system/zone interrelationship is directly established on composite arrangements. Composite drafts are also prepared by experienced designers to identify arrangement patterns, which are to be repeated during the preparation of composite arrangements. Thus, composite drafts are normally employed only during transition design.

During the preparation of composite drafts, transition designers typically consider:

- for operating and maintaining a ship:
 - specified systems' capacities
 - accessibility
 - proximity of hull structure
 - orientations of pipelines (such as needed slopes of scupper drains, elimination of U-bends, and placement of bilge suctions)
- for productivity:
 - how to facilitate manufacturing and fitting
 - rigidity and compactness of outfit components
 - usage of hull structural members for outfitting
 - minimizing on-board outfitting
 - maximizing the use of straight pipe pieces to minimize bending work
 - limiting pipe bends to 90 degrees and, when other bends are necessary, to 45 degrees as much as possible
 - arranging pipe lines in parallel so that they can share common pipe supports
 - avoiding arrangements which follow hull curvature
 - maximizing pipe piece lengths to minimize the number of pipe joints
 - observing weight and size limitations for outfitting on-unit and on-block (such as crane capacities and shop door sizes)
 - avoiding the location of components on or near erection butts and seams
 - avoiding the location of outfit units astride erection butts and seams
 - providing for adjustable pipe pieces to be fitted on-board

2.3.3. Composite Arrangements. Composite arrangements portray exact positions and identities of outfit components and pipe, ventilation duct, and wireway paths in accordance with composite drafts or otherwise, directly in accordance with the pallet list. Considerations include sizes and weights of fittings and nature of the work involved as well as

the considerations listed for composite drafts
Items which are defined include:

- three-dimensional locations of certain components, such as machinery, other equipment, foundations, ladders, access ways, handrails, and pipe, vent duct, and electric cableway paths
- piece numbers for the separable components, less those for distributive systems
- pipe, duct, and wiring system codes
- instructions for locating flanges that affect functional aspects of pipe and duct systems, such as flanges necessary for maintenance
- instructions for locating flanges relative to erection butts and seams

Beyond division by outfit specialty, composite arrangements are further subdivided in accordance with a practical scheme such as the one below:

- hull group
 - forward upper deck
 - middle upper deck
 - after upper deck
 - forepeak tank
 - cargo hold or cargo tank (bottom, transverse bulkhead, and longitudinal bulkhead)
 - pump room (tankers only)
 - steering gear room
 - afterpeak tank
- machinery group (engine room, casing and funnel only)
 - tank top
 - second deck flat
 - upper deck
 - engine casing
 - funnel
- superstructure group
 - A-deck (upper deck)
 - B-deck
 - C-deck
 - D-deck

- navigation bridge deck
- compass bridge deck

Also, for the machinery space levels, the composite arrangements are separately prepared for decks and overheads.

Ideally, the zone-by-zone composite arrangements would show all fittings within each zone. As such composites for congested regions, like an engine room, are difficult to prepare and decipher, they are separately produced by grouping fitting types. Groupings that have been found to be practical are:

- machinery and piping
- access ways, including ladders and floor plates
- ventilation ducts

A useful scheme for combining different types of outfitting materials to be shown on composite arrangements is illustrated in Figure 6-18. In shipyards where there is significant development of standard symbols, descriptions, components, etc., some composite arrangements are simple enough to be used directly as work instructions. A typical composite arrangement prepared by a hull outfitting design group is shown in Figure 6-19.

COMPONENT	SECTION		
	H	M	S
AUXILIARY, VALVE, ETC	•	•	•
PIPE PIECE AND SUPPORT	•	•	•
ACCESS FLOOR PLATE AND LADDER	•	•	•
VENTILATION DUCT AND SUPPORT	•	•	•
OTHER COMPONENT	•	•	•
LINING			•
FURNITURE			•
ELECTRIC WIRE	• (E)	• (E)	• (E)
CABLE CONDUIT	•		
WIRE WAY, SUPPORT AND SEAT	• (E)	• (E)	• (E)
ELECTRIC EQUIPMENT	• (E)	• (E)	• (E)

Fig 6-18. Separation of types of outfitting materials on composite arrangements

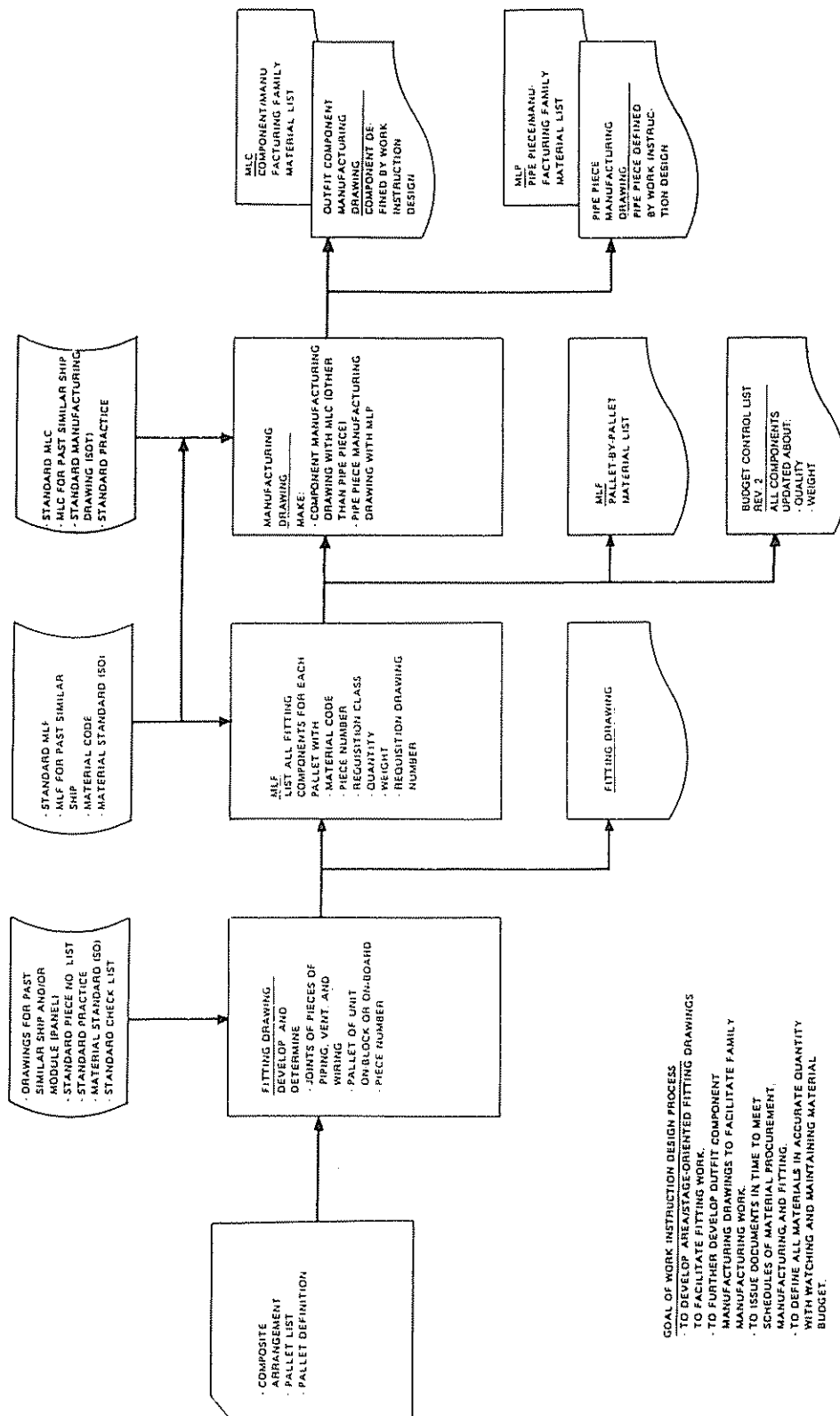


Fig. 6-20. Work instruction design responsibilities.

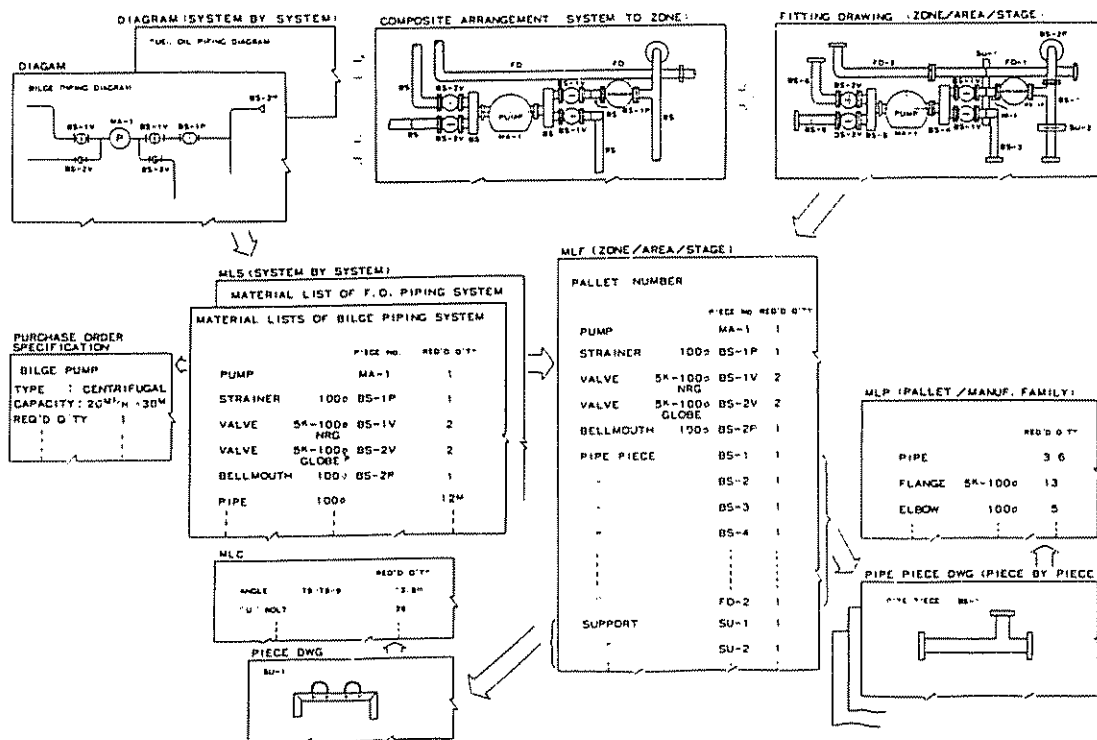


Fig 6-21. Coordination of design and material definition

2.4.1 Fitting Work Instruction Drawings. Preparation of fitting work instructions involves piece-by-piece definition of all fittings not previously defined, such as exact definition of pipe pieces and pipe supports, final definition of each pallet by the production aspects which characterize the production processes (problem area and stage), and production of material lists for fitting (MLF) by pallet.

Considering the outfitting stages and flows of outfit components to be issued, as illustrated in Figure 6-22, the composite arrangements are used to make decisions regarding fitting stages for components and for joints in distributive systems needed to facilitate on-unit and on-block outfitting. Then, using hand-marked or computer-generated drawings, components selected to be fitted on-unit, on-block, and on-board are identified.

These composite arrangements are supplemented with:

- pallet numbers, which are code numbers identifying zone/problem area/stage for each pallet
- all joints not previously defined in distributive systems
- supports for distributive systems
- piece numbers identifying each piece of and support for distributive systems
- dimensions of auxiliary machinery foundations

Because of its derivation by stage from composite arrangements, each fitting work instruction drawing generally includes several pallets.

2.4.2. Material Lists for Fitting (MLF). Upon completion of each fitting instruction drawing, all outfit components required by pallet are listed on the MLF. The rather extensive descriptions include:

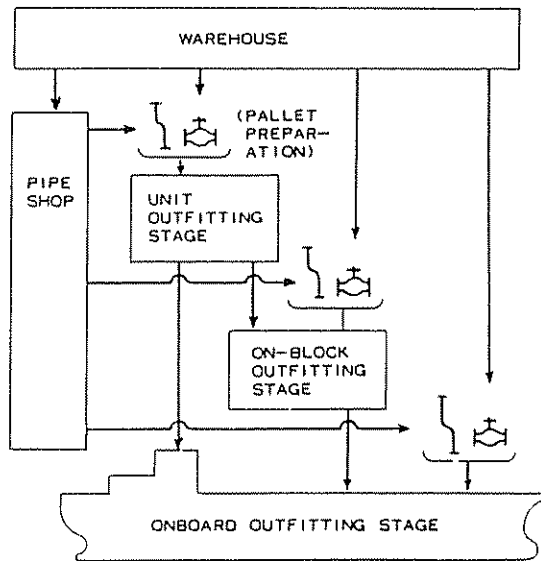


Fig. 6-22 Stages for outfitting components

- material code
- piece number
- material cost classification number
- material listing classification
- material requisition classification
- material control classification
- material purchasing classification
- parent/child sign
- weight
- quantity
- MLF zone
- drawing number corresponding to procurement and fitting work

With respect to a specific zone/problem area/stage, each MLF is used for collection (palletizing) of outfit components in anticipation of fitting work, recording the weight of outfit components to be used for calculating the pallet's fitting work content and contribution to ship's outfit weight, and updating the material identification status.

Material definition is the key to efficient production. Therefore, providing information for each fitting is an important and extensive task. These MLF data are compared with in-

ventory and requisition status by material control personnel in the production control department, to ensure that all material needs are anticipated. Standardization of fittings and computerization to facilitate material sorting and collating by the various classifications is virtually indispensable. The computer program for sorting and collating material consistent with the foregoing may be the most important program in shipbuilding.

2.4.3. Manufacturing Work Instruction Drawings. Items listed on MLF which must be custom manufactured are described in manufacturing work instructions in sufficient detail to permit either in-house or outside manufacture. Major items, such as masts, booms, and unique tanks, which require long lead times for procurement of raw materials or for manufacture, are identified during the functional design process and treated as exceptions.

In addition to the major items, each pallet generally contains various piece parts, including pipe pieces, ventilation duct pieces, ladders, access way pieces, handrail pieces, and supports. Manufacturing drawings are prepared for each component by pallet by kind of item, in accordance with the grouping of components in pallets on fitting drawings. Thus, all of the manufacturing drawings for components of one kind within a pallet are grouped so that they can be assigned for manufacture by pallet regardless of where they are to be manufactured.

Components, other than pipe pieces, of one kind are almost always of the same manufacturing family and require the same lead times. Thus, all such components can be included in a single manufacturing drawing. Drawings by kind of item by pallet facilitate issuing work orders and just-in-time manufacture of the required items.

Usually, the pipe pieces within a pallet represent different manufacturing families and have different lead times. Thus, pipe

pieces by pallet are further grouped by pipe piece family. This permits sorting, ideally by computer, so that the starts of manufacture of the pipe pieces requiring the long lead times are commensurately earlier to ensure that all pipe pieces required for a pallet are available at the same time for fitting work.

2.4.4. Material Lists for Manufacturing (MLP and MLC). Upon completion of each manufacturing instruction drawing, all raw materials are listed on MLP and MLC for manufacture of pipe pieces and components other than pipes, respectively. The rather extensive descriptions presented in Subsection 2.4.2 are employed but are relatively easy to incorporate through standardization and computer programs. Similarly, the data on MLP and MLC, both for parent and child, are again compared to MLS, inventory, and the requisition status and are employed to refine outfit weights and the predicted amounts of fitting work. These data are used to predict the amounts of manufacturing work required.

2.5. Mold Loft Interface

Mold loft work is commonly begun during transition or work instruction design. The

function of the loft may be considerably expanded from traditional lofting. The computer capability available in the mold loft makes it an obvious location for the production of work instructions, material lists, pallet lists, schedules, etc. These responsibilities are in addition to the standard loft work of steel parts programming, development of N/C burning data, and development of templates. Many of these are based on information generated elsewhere and simply provided in hard copy by the mold loft computer. The outputs of the mold loft may include:

- key plans (see Figure 6-23)
- yard plans (see Figure 6-24)
- work instructions (see Figures 6-25 and 6-26)
- material lists (see Figure 6-27)
- material lists by pallet (see Figure 6-28)
- schedules (see Figure 6-29)

Additionally, the mold loft may produce templates for line heating (Chapter IV), pin jig settings (Chapter V), and accuracy control check sheets (Chapter VIII). In general, this information should be provided in the form of booklets or manuals that permit routing of pertinent pages only to the workstation where it is needed (see Figure 6-30).

3. Design and Engineering for Production

The inputs of engineers to the ship production process take many forms. Perhaps the simplest way to subdivide these are in terms of design and engineering. Design includes the system-oriented outputs of the basic and functional design stages. Engineering is then the detailed breakdown of the design into product-oriented yard plans and work instructions, or the description of precisely how the ship will be built. In either application, the principles of design/engineering for production are similar. Although good design/engineering should always take into account

the production techniques, this goal has often been inadequately addressed. Consequently, some general principles can be developed to improve the consideration of production efficiency in the design process. The goal of design and engineering is the reduction of the cost of production to the minimum possible, subject to satisfying design performance and quality requirements. The use of concurrent or simultaneous design principles, in which teams of specialists work together to continuously consider design, production, purchasing, performance, and other factors, is an

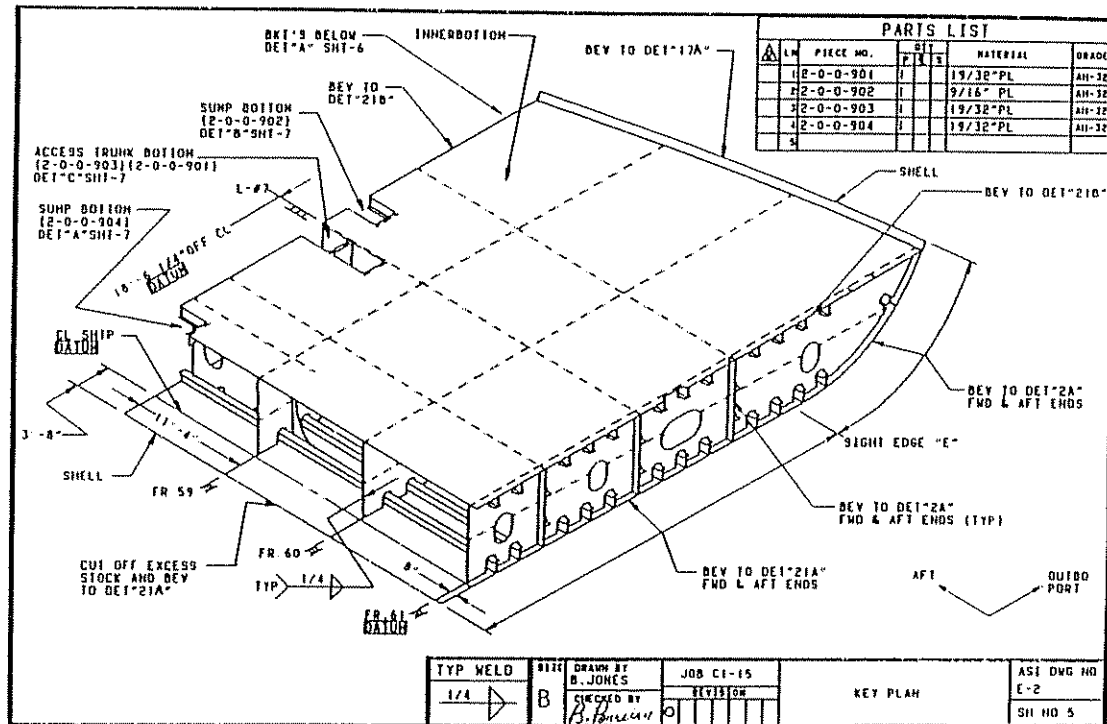


Fig 6-23. Mold loft-generated key plan.

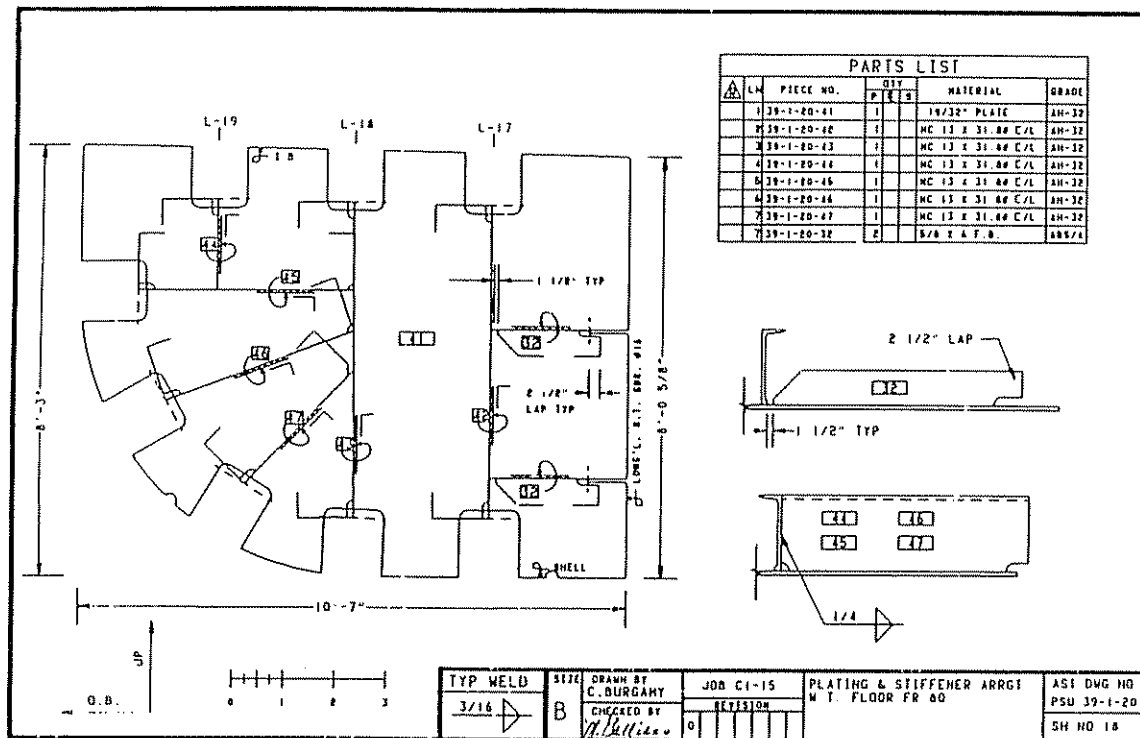


Fig 6-24. Mold loft-generated yard plan.

UNIT #105 (CATEGORY #1) WGT. (TONS)	DATE: 03/09/82	REV. #1
TRANS. O.T. CORRUGATED BHD. FR. 89.		
HULL "B" & "H" ONLY		
(DWG. OG-104-000)		
A. PARTIAL SUB UNIT #105-001-001		
WORK CENTER - PLATEN #24		
FABRICATE (6) BKTS. DET. THEN SEND THEM TO PLATEN #20 SUB ASSEMBLY STAGE.		
B. SUB UNIT #105-001		
WORK CENTER - PLATEN #20 - SUB ASSEMBLY STAGE		
SUB ASSEMBLE THE CORRUGATED BHD. PLATE FR. 89 WITH FWD. SIDE UP		
FABRICATE AND SUB ASSEMBLE THE CL. BHD. DET. SUB ASSEMBLE (4)		
FABRICATED BKTS. (P.S.U. #105-001-001), STRONGBACK BHD. AND TURN IT		
OVER. SUB ASSEMBLE TOP AND BOTTOM BKTS. (2) FABRICATE BKTS.		
(P.S.U. #105-001-001) AND F.B. HEADERS. WHEN COMPLETE MOVE TO		
PRE-OUTFIT STAGE ON PLATEN #20 IF REQ'D.		
D. UNIT #105		
WORK CENTER - PLATEN #20 - PRE-OUTFIT STAGE		
PRE-OUTFIT IF REQ'D THEN MOVE IT TO PLATEN #20 FINAL ASSEMBLY STAGE		
E. UNIT #105		
WORK CENTER - PLATEN #20 - FINAL ASSEMBLY STAGE		
CALL OUT FOR A.S.I. OWNER STRUCTURAL INSPECTION, COMPLETE PICK UP		
WORK, THEN SEND TO BLAST AND PAINT.		

Fig. 6-25. Mold loft-generated work instruction.

PIPE SHOP ROUTING			CLASS 1 11 XX PIPE SHOP USE ONLY		P.D. NO. 14-4	
DESCRIPTION	WORK STATION PLANNED/NEXT		W.D. 1	W.D. 2	NO. REQ'D	NO. REC'D
00061413						
00062208						
CLEAN EXTERNAL	2 1	2 2				
CLEAN INTERNAL	2 2	17 8				
00062208						
STONE SAW - 3"	17 8	4 1				
00061413						
SAW CUT 2"-14"	4 1	11 1				
CL3						
4" BENDER (CONRAC)	11 1	9 5				
00070113						
00074608						
00127604						
00130213						
CL1, CL2						
SUB ASSEMBLY	9 5	18 2				
GALVANIZING	18 2	13 1				
PALLETIZING	13 1	14 1				
STORAGE	14 1					

		CL1=5.6775 - 11 1/2" CL2=5.6775 - 11 1/2" CL3=174.5457 - (4-) DR1 W1 = 236 2108 WET W1 = 309 8818
00061413 PIPE STL SHLS SCH 80 (XS) ASTM A53 GR B 4"		
00062208 PIPE STL SHLS SCH 80 (XS) ASTM A106 GR A 6" B 1 1/2"		
00070113 1 FLANGE STL SLIP-ON 150 ASTM A105 ANSI B1 6 5 RF 4"		
00074608 2 FLANGE STL SOCKET WELD 150 ASTM A105 ANSI 1 B16.5 XS MORE FF 1 1/2"		
00127604 1 COUPLER STL FORGED SW 3000 ASTM A105 V06 1 SW 1211 1/2"		
00130213 1 CAP STL BW XX ASTM A234 ANSI B16.9 4"		
CDST	P.D. BOX 50260 NEW ORLEANS, LA. 70150	
0603	TITLE: HW DR. RACK PIPING STD SIDE FR 70-73 PACKAGE UNIT HULL "B" ONLY	
	JOB NO. E1-15 DWG NO. 11 618 01 DWN 1.1.1 REVISION 1	

Fig. 6-26. Mold loft-generated work instruction plan.

LIST OF MATERIAL			QUANTITY (1) SHIP	REQ.NO
C. MK	QTY.	DESCRIPTION	UNIT PRICE	
0017034	2	VALVE HOSE ANGLE BRZ FLG 150# MONEL STEM W/MOLDED COMPOSITION W/BRZ DISC HOLDER FURNISHED W/BRZ SLOTTED CAP & CHAIN 1 1/2 9NM APPLIES TO HULL 1 ONLY ***** PALLET CODE FOR THIS ITEM = 0603 901 1R		
0040225		VALVE GATE STN STL TY 316 FLG 150 STN STL TRIM UNION BONNET + 3/4 SUB-ALLOCATION NO. GROUP QTY/SHIP PALLET CODE VES HULL NO(S) 1 2 0602 901 1 1 1 ONLY 2 2 0611 901 1 1 1 ONLY		
0056027	5	VALVE BALL STM STL 316 BODY SW END CONN 316L W/TEFLON SEAT & SEAL FIRE SAFE MARPAC TR1-PAC SS-B325-TT P-NS2 -1 1/2 APPLIES TO HULL 1 ONLY ***** PALLET CODE FOR THIS ITEM = 0602 901 1R		
0060826	21"	PIPE STL SMLS SCH 80 ASTM A 53 GR B APPLIES TO HULL 1 ONLY ***** PALLET CODE FOR THIS ITEM = 0602 901 1	16	
0061311	38"	PIPE STL SMLS SCH 40 (STD) ASTM A 53 GR B APPLIES TO HULL 1 ONLY ***** PALLET CODE FOR THIS ITEM = 0611 901 1	3	
AVONDALE SHIPYARDS, INC. P.O. BOX 50280 NEW ORLEANS, LA 71050			CUSTOMER	EXXON INT CO
TITLE MV.DK. RACK PIPING STBD. SIDE FR.70-73 PACKAGE UNIT L/M			JOB NO	C1-0015
			DWG.NO	9I 61B 016

Fig 6-27. Mold loft-generated material list

MATERIAL LIST (QUANTITIES FOR ONE SHIP)

ITEM NO.	QUANTITY	DESCRIPTION	MATERIAL	SPEC ORD DATA	UNIT WEIGHT	ASI SYD PT NO	REMARKS
1	27	TREADS 9" x 24" (1 1/2" HOSENO RISER)	STEEL	ASTM A-36	6.7 PER 56 FT	N/A	RAISED PATTERN FLOOR PLATE RYERSON OR EQ
2	3	HANDGRAB-BAR 5/8" DIA			1.043 PER L/F	N/A	ASI STD DWG MS-16-HL-1 (TYPE 3)
3	88	BOLT, HEX HD 3/4"-10UNC-2A 2 1/4" LG	STN STEEL	TYPE 316	0.3768 PER ONE	LATER	
4	82	LOCKWASHER 3/4" SPRING (MED)			0.0876 PER ONE	10100-52-83	FOR PC NO 3 & 14
5	82	NUT, HEX 3/4"-10UNC-2B			0.1876 PER ONE	10100-30-10	FOR PC NO 3 & 14
6	42 L/F	ANGLE 2 1/2" X 2 1/2" X 1/4"	STEEL	ASTM A-36	4.1 PER L/F	2-A36-519	
7	7.25 L/F	FLAT BAR 3" X 3/8"			3.83 PER L/F	2-A36-840	
8	251.5 L/F	FLAT BAR 2 1/2" X 1/2"			4.25 PER L/F	2-A36-035	
9	0.5 L/F	FLAT BAR 2 1/2" X 1/4"			2.13 PER L/F	2-A36-032	
10	161 L/F	SQUARE BAR 3/4" TC CUT 17 1/2" LG.			1.91 PER L/F	2-A36-905	109 @ 17 1/2" LG.
11	84 L/F	CHANNEL CB X 10.5			10.5 PER L/F	2-A36-1408	
12	154 L/F	PPE, 1 1/4" STD		ASTM A-53	2.27 PER L/F	000080107	
13	15	TREADS 9" x 18" (1 1/2" HOSENO RISER)		ASTM A-36	6.7 PER 56 FT	N/A	RAISED PATTERN FLOOR PLATE RYERSON OR EQ
14	18	BOLT, HEX HD 3/4" - 10 UNC - 2A 2 1/4" LB	STN STL	TYPE 316	0.3377 PER ONE	10100-52-69	
15	30 1/2 Y.	SHEET METAL 16 GA.	37" GALV. STEEL	CUM'L	2.5 PER 50 FT	LATER	1 PLATE AT 18" x 9" x 2" x 16" CUT & WELD TO SUIT
16	18	BOLT, HEX. HD., 3/4" DIA - 2 UNCS 2A 4" LG		ASTM A-307 GR. B	0.17 PER ONE	10101222	
17	18	NUT, HEX., 3/4" - 20 UNC 2B			0.07 PER ONE	LATER	AS PC NS16
18	18	LOCKWASHER, 3/4" DIA (SPRINGS TYPE AND)		ASTM A-307 GR. B	0.08 PER ONE		
19	18	BEVELD WASHER, 3/4" DIA		ASTM A-307 GR. B	0.04 PER ONE		

Fig. 6-28 Mold loft-generated material list for a pallet.

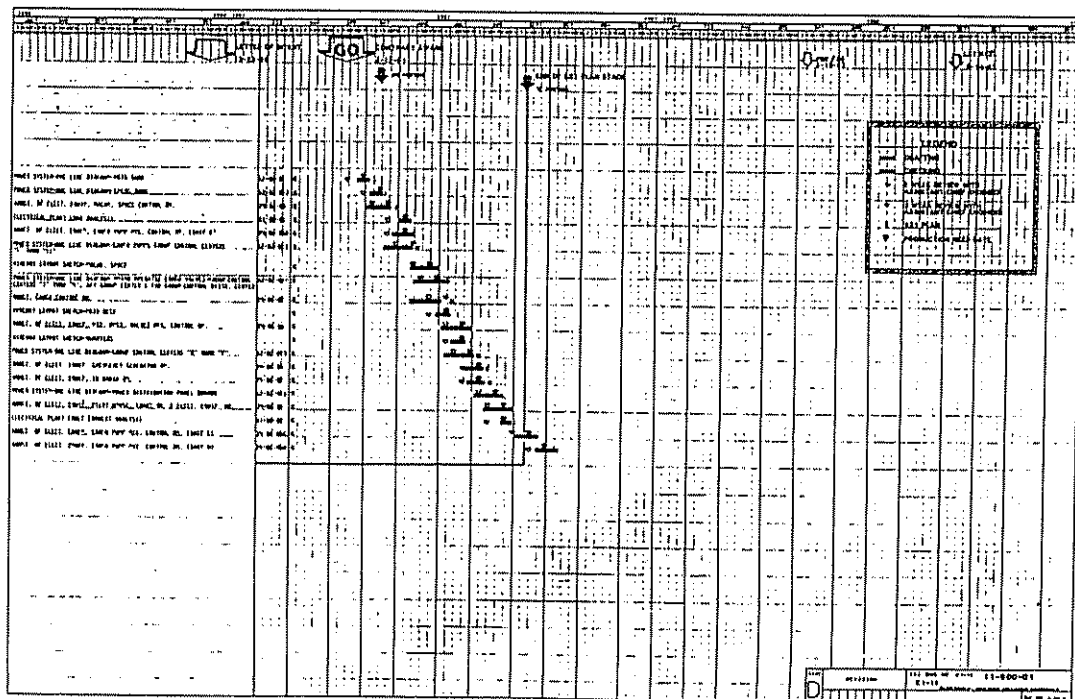


Fig. 6-29 Mold loft-generated schedule.

REV		NO	TITLE	DRAWING NO	REV
3			PIPING MAT'L SCHEDULE	06-00-10	91-618-016
2			BOLT NUTS + GASKET STD FOR PIPE FLANGED JOINT (THRU 300)	MECH STD NO. 37	
1			MN DX P&CK PIPING STBD. SIDE FR. 70-73 PACKAGE UNIT - HULL "B" ONLY	91-618-016	
REFERENCES					
RECORD INFO					
THIS DRAWING FOR					
ASI HULL 2335 JUN 25 1992					
SHIP B ONLY					
NAME OF VESSEL					
AVONDALE SHIPYARDS INC					
P O BOX 50280 NEW ORLEANS, LA 70150					
A S I JOB NO					
C1-15					
EXXON COMPANY, USA					
42,000 DWT MULTI-PRODUCTS CARRIERS					
MN DX P&CK PIPING STBD. SIDE FR. 70-73 PACKAGE UNIT					
DRAWN BY DATE					
RSP 11-2-81					
CHECKED BY DATE					
F.V.C.					
APVD					
MECH. ENGINEER					
APVD					
ASST. CHIEF ENGINEER 12-7-81					
APVD 12/9/81					
A. B. Ekelund					
SIZE					
A C1-15 91-618-016					
SCALE					
SHEET					

Fig. 6-30. Information booklet title page.

approach to design for production that offers great promise for future application.

3.1. General Principles

The general principles of design for production can be summarized in the following five points:

- use common sense
- plan and define
- base design on available facilities and tools of production
- simplify
- standardize

In applying these principles, the system outlined in Figure 6-31 has been proposed to im-

prove consideration of production factors. [4] In each design stage, an appraisal technique can be applied to determine if the proposed design has satisfactorily accounted for operating and production factors in addition to performance requirements and technical criteria. This appraisal technique must include specific consideration of the production costs of various design alternatives. Consequently, it is most likely to be effective if applied to specific blocks and outfit units for which estimates of construction times and costs can be readily made. As shipyards develop experience in productive construction techniques by problem area (such as double bottoms, slow-speed diesel engine rooms, etc.), engineers will be di-

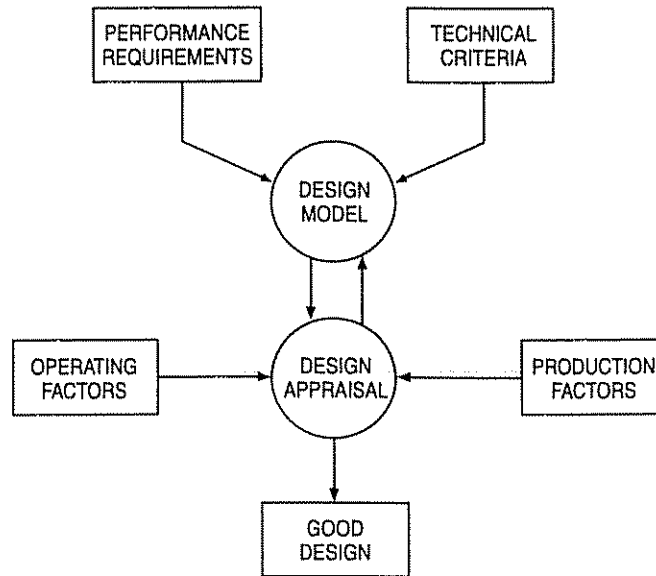


Fig 6-31 Improved design approach

rected toward more productive designs, beginning with basic design. Figure 6-32 indicates typical design and production information used to improve design at each design stage.

For new or unusual designs, or for shipyards without sufficient information to formulate and analyze designs using a formal, quantitative model for comparison, the qualitative principles provided above form a basis for evaluating design and engineering. In applying these principles, the following steps may be taken: [5]

1. Examine existing design.
 - Count the number of unique parts
 - Count the total number of parts
 - Count the number, type, and position of joints
 - Evaluate the complexity of the design
 - simple measuring
 - simple manual layout
 - complicated manual layout
 - CAD/CAM applicability
 - required manual processing
 - required machine processing
 - Producibility aspects
 - self-aligning and supporting

- need for jigs and fixtures
 - work position
 - number of physical turns/moves before completion
 - aids in dimensional control
 - space access and staging
 - standardization
 - number of compartments to be entered to complete work
2. Examine alternative design in the same manner

3.2. Standardization

Standardization is the principle of design for production that is likely to lead to significant improvements in productivity. Throughout the discussion of group technology and PWBS, the concept of organization of work by problem area is developed. In essence, the goal is to achieve repeatability in a manufacturing situation characterized by one-of-a-kind products. The same consideration applies to design. The goal is to develop a group of standard building blocks that can be combined to produce very different final products.

Standardization in shipbuilding is applied in several steps, beginning with elementary

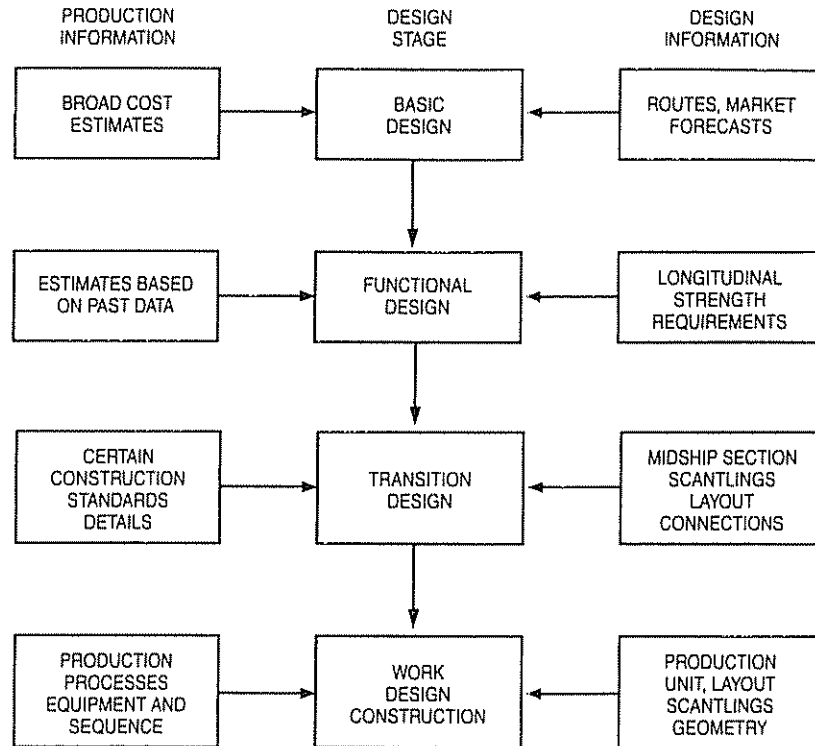


Fig. 6-32. Design and production information useful for improving design at various stages

components, assembled units, and ultimately a complete ship design. Since the shipbuilding market is likely to continue to be characterized by varying and individual product requirements, a standard ship series may not be feasible. Consequently, efforts at design standardization should be concentrated at the component, subassembly, block, and outfit unit (design module) levels. In establishing standards, it is important to realize that a non-standard category and nonstandard design options must be part of the system.

Standards may be classified in two groups. [6] These are basic standards and standard drawings (see Figure 6-33). The basic standards include material and component standards, outfitting standards, design standards, production engineering standards, and inspection standards. These can be considered at two levels. Material and component standards cover hardware items such as steel plate and sections, valves, pipe pieces, doors, and

ladders. Outfitting and design standards use standard materials and components in a repeatable way to form subassemblies and outfit units. Production engineering standards describe the procedures and processes of production work, while inspection standards detail procedures for accuracy control and testing and inspection.

Standard drawings show typical subassemblies and outfit units that may be used directly on new designs or as guidance in preparing new drawings based on standard approaches. Figures 6-34, 6-35, 6-36, and 6-37 are examples of standard drawings for a structural assembly, machinery arrangement, piping layout, and outfit unit, respectively.

3.3. Logic of Design

A key element in design to support group technology shipbuilding is consideration at each design stage of productivity and the impact of the design and the design process on

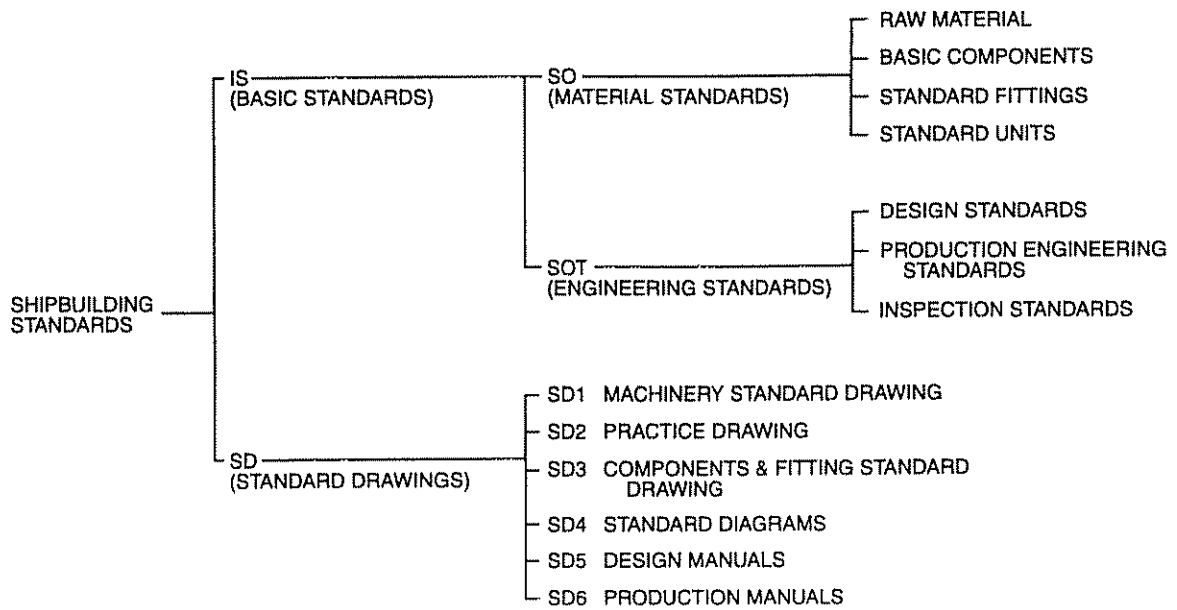


Fig. 6-33. Classification of standards.

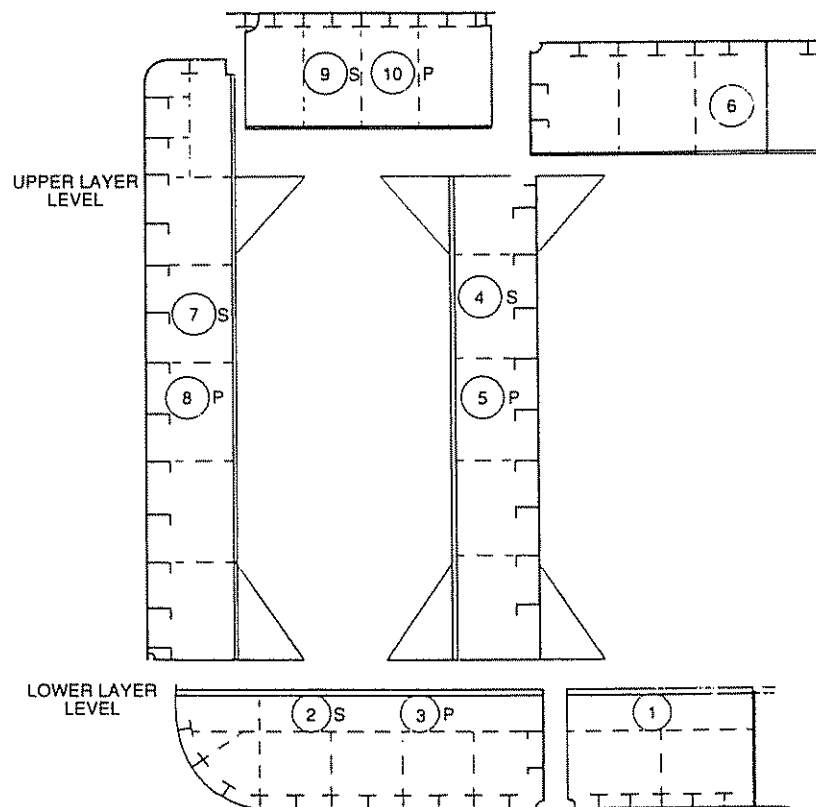


Fig. 6-34. Standard structural assembly detail.

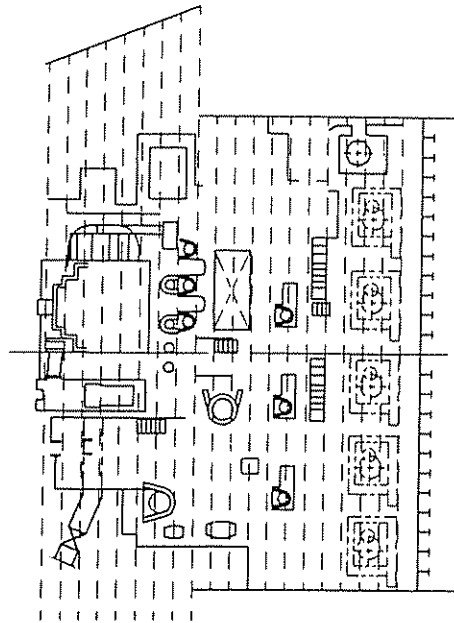


Fig 6-35 Standard machinery arrangement module.

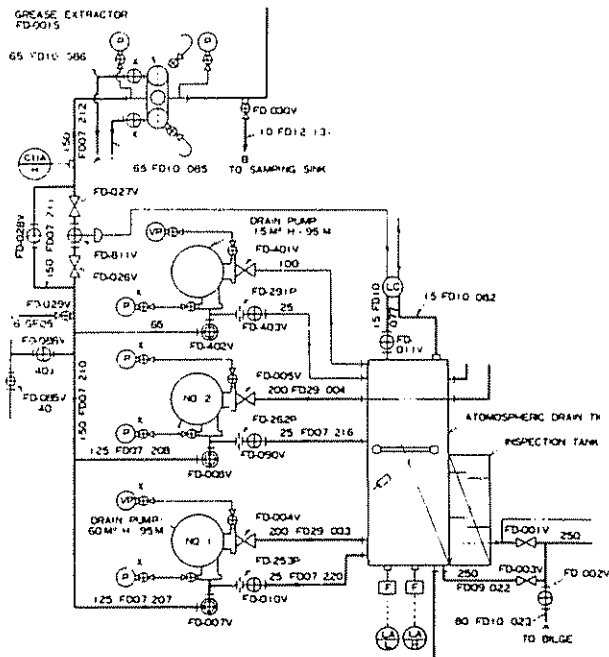
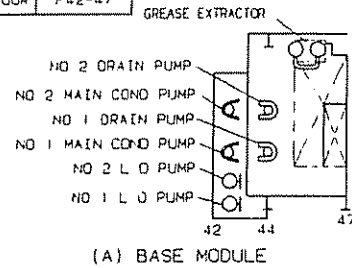


Fig 6-36 Standard piping layout module.

production. Approaches that provide enough information at the proper time in the proper form are essential.

FLAT NAME	DIVISION
MAIN FLOOR	F42-47



FLAT NAME	DIVISION
MAIN FLOOR	F42-47

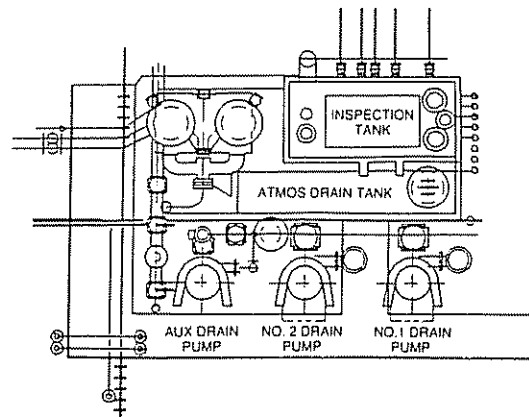
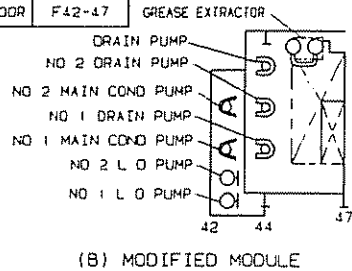


Fig 6-37 Standard outfit unit module

3.3.1. Zone Orientation. The most important principle in zone-oriented design is that material which is first assigned by function (system) is reassigned geographically. The reassignment is made for the convenience of workers by specifically defining the material required to do an amount of work in a specific zone during a designated stage. When the work so defined is classified by a problem category,

all aspects exist for defining a pallet by zone/problem area/stage. This entails grouping information by pallet on a set of documents as follows:

- fitting instruction, a composite arrangement indicating the locations of fittings
- material list for fitting (MLF), identifying the fittings necessary to perform the work specified by the pallet
- manufacturing instructions and their material lists (MLP and MLC), which are necessary to custom manufacture certain fittings that are listed in the MLF, such as pipe pieces, ladders, or drain collecting tanks

On such documents, material is attributed only to location. Manufacturing and fitting workers are not encumbered with material assigned by function. For example, a stop valve for a fuel oil transfer pump is coded as a component for a specific zone/problem area/stage by a piece number and pallet number. Designating the valve as one of the valves in the fuel oil piping system is extraneous and requires more understanding than is necessary for manufacturing and fitting work. Thus, piece and pallet numbers are used for identifying materials on work instructions, on material lists, during palletizing, and during outfit work on-unit, on-block, and on-board.

Following such fitting work, there is often need for function identification, such as for marking and testing work. Thus, the employment of piece numbers coded to identify functional as well as geographical attributes is prudent.

Material assigned geographically frees manufacturing and fitting workers from the need to comprehend relatively complex knowledge of the purposes of fittings. They need only understand the association of piece numbers with fittings illustrated on a drawing to match the numbers to those on fittings in a provided material kit (pallet) and install

the fittings exactly as shown on the drawing. Well-planned piece numbers can sometimes convey a required or recommended fitting sequence (see Figure 6-38). With such planning performed for them, workers are then able to concentrate on understanding the work processes so that they may better participate in efforts to constantly improve productivity and quality.

3.3.2. Design Development by Zones. The same principle which governs grouping material by zone leads to development of the portions of all systems in a zone at the same time. In contrast, conventional design progresses system by system, ignoring zone-by-zone hull construction, which is universal for constructing welded hulls. Thus conflicts are inherent in any outfit strategy which is not zone oriented. Due to different priorities, valuable time is used at the beginning of a system-by-system detail design effort developing portions of systems that will not be needed for some time.

Scheduling of design development work must be done so that information is grouped by zone. For example, pipe runs in the same zone, regardless of their system affiliations, are developed at the same time and are arranged parallel to each other wherever possible. This is an essential means for shifting much fitting work from inefficient piece-by-piece outfitting on-board to outfitting on-unit in a shop where safety, quality, and productivity are enhanced. Thus, planning pipe routes, pipe piece types, and locations of pipe supports on fitting instructions is a very important function. Such concerns must be reflected in contract drawings, such as general and machinery arrangements, after careful and comprehensive planning. Approaches for achieving zone orientation include:

- showing pipe passages reserved for multiple pipe runs on contract arrangements, particularly in congested zones

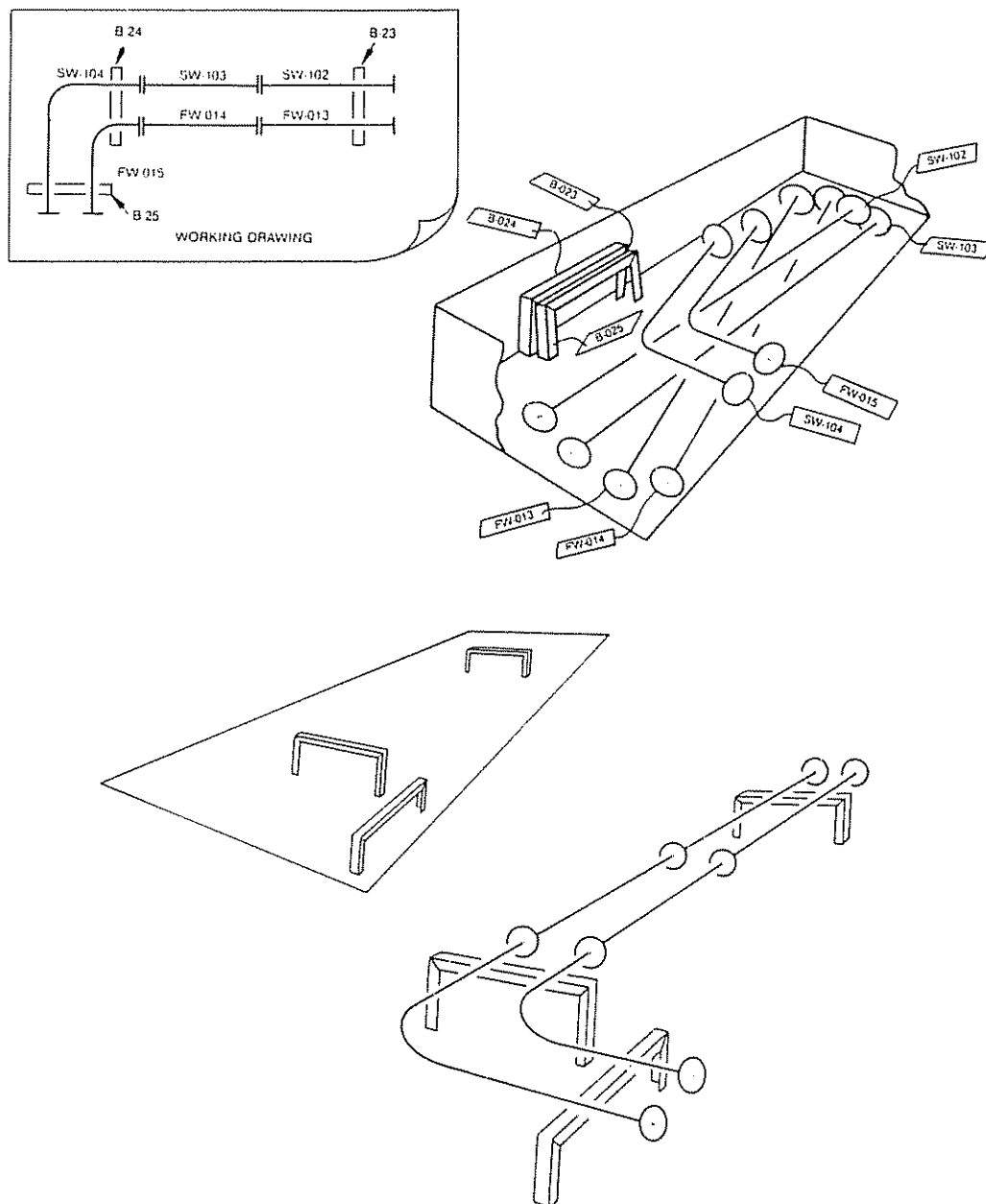


Fig. 6-38 Use of geographical arrangement of material.

such as around a main engine or ship's service generator, or in double bottoms and living quarters (see Figures 6-39 and 6-40)

- aligning pipe runs parallel to the ship's X, Y, and Z axes, as shown in Figure 6-41, to achieve consolidation of pipe

pieces for efficient assembly on-unit instead of "tangled spaghetti" pipe runs that must be assembled piece by piece on-board

- detailing common supports for multiple pipe runs on work instructions (see Figure 6-42)

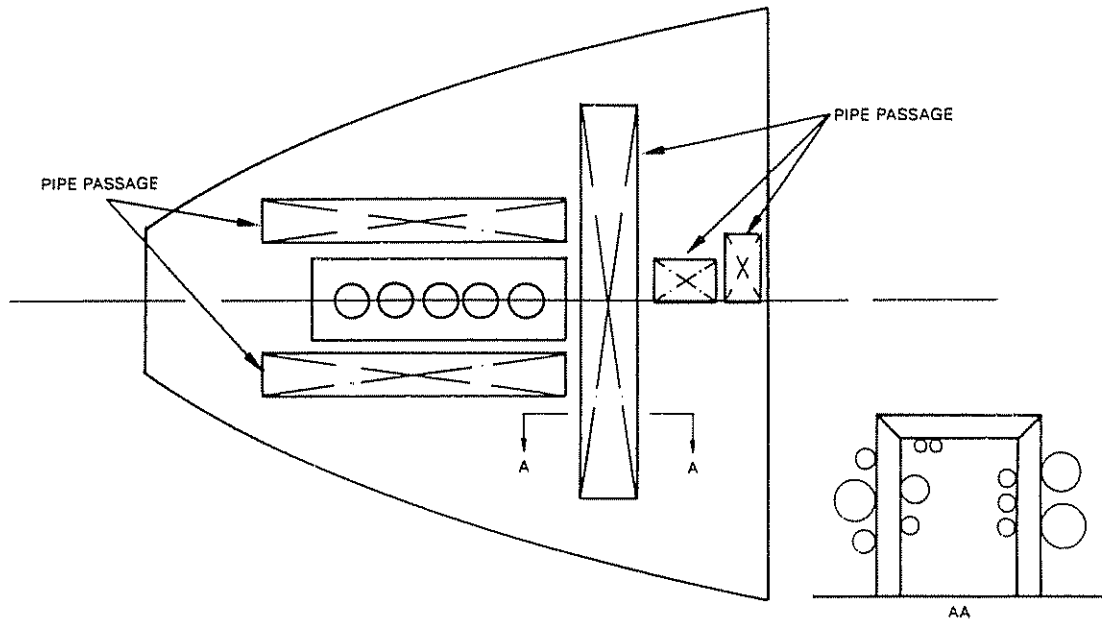


Fig. 6-39. Pipe passages reserved for multiple pipe runs.

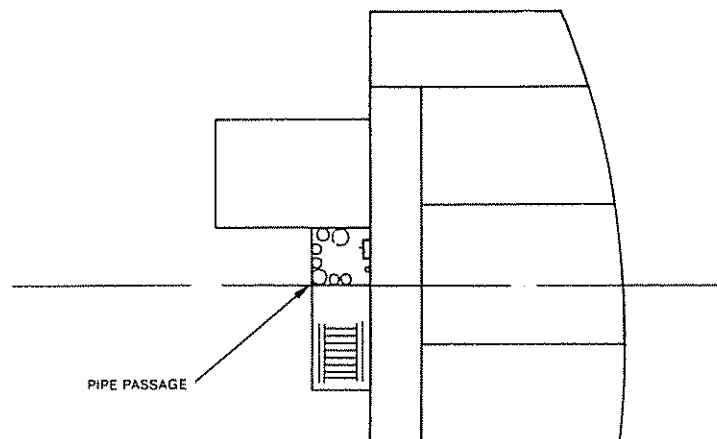


Fig. 6-40. Pipe passages reserved for multiple pipe runs.

- aligning pipes on their outside diameters instead of their centerlines (see Figure 6-43), to simplify supports

3.3.3 Product Orientation. Group technology shipbuilding is product oriented. Items such as pipe pieces and outfit units are regarded as interim goals or interim products and are manufactured or assembled on real or virtual production lines (process lanes).

All machinery, equipment, and pipes are arranged to ensure minimum production costs with special emphasis on man-hours required. This objective is achieved by applying the principle that performing outfit work at the earliest stage, on-unit, costs less, whereas performing outfit work on-board is harder and most expensive. The following are some outfit measures applied to reduce costs and make work easier:

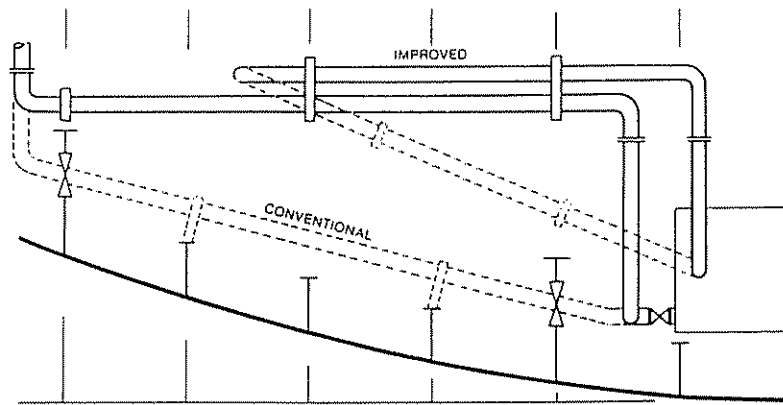


Fig. 6-41. Pipe runs parallel to XYZ axes

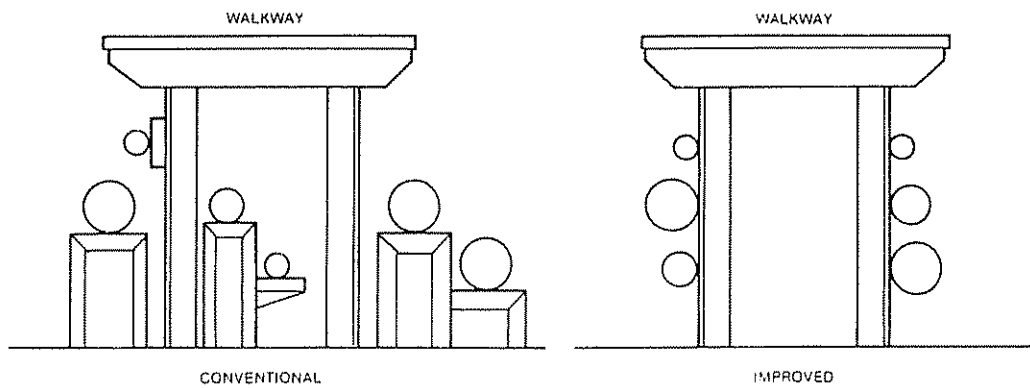


Fig. 6-42 Common supports for pipe

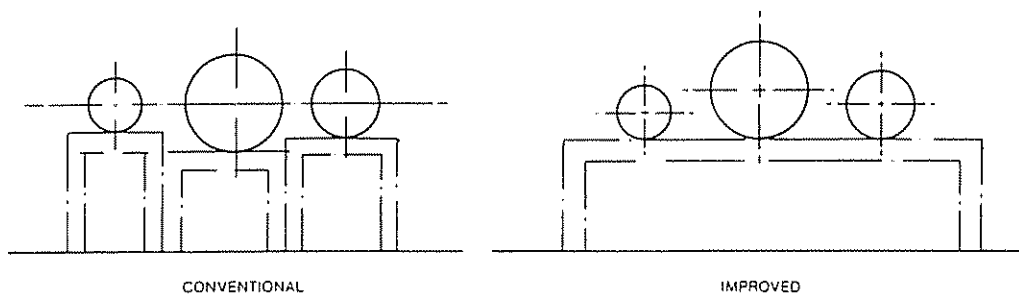


Fig. 6-43. Pipe supported on common edges

- machinery and equipment which are functionally affiliated are, when practical, arranged close together (see Figure 6-44), to facilitate packaging in units
- common foundations are used for such machinery, and immediately adjacent walkways and piping share common supports

- as far as practical, pipe bends are restricted to 90 and 45 degrees, as a means for achieving accuracy in joints between pipe pieces, units, and between pipes and machinery
- even pipes which simply pass through a zone for a contemplated outfit unit are designated as part of the unit for outfitting on-unit (see Figure 6-45)
- as far as practical, small tanks and foundations for machinery and equipment are designed to be independent of hull structure (see Figure 6-46)

- pipe pieces which are to be installed on-board are limited in both length and weight, for ease of handling by one worker
- pipe pieces by pipe piece family by ship are recorded so that managers can constantly strive to reduce the total number of pipe pieces and the percentages of the more expensive pipe piece types

3.3.4. *Hull Structural Design to Facilitate Outfitting* Group technology shipbuilding employs integrated hull construction, outfit-

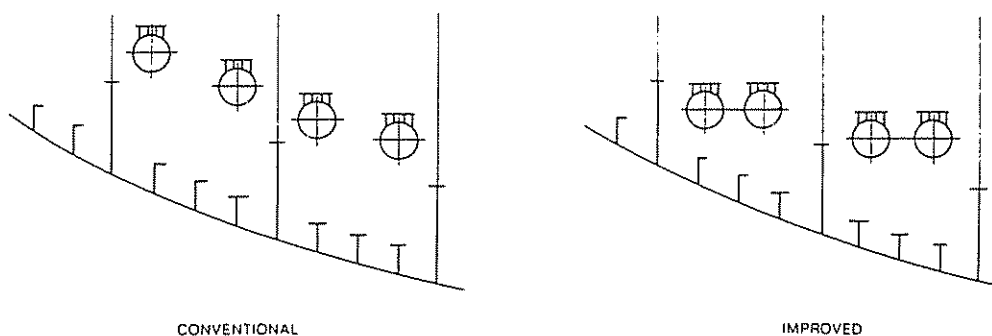


Fig. 6-44 Components aligned side by side.

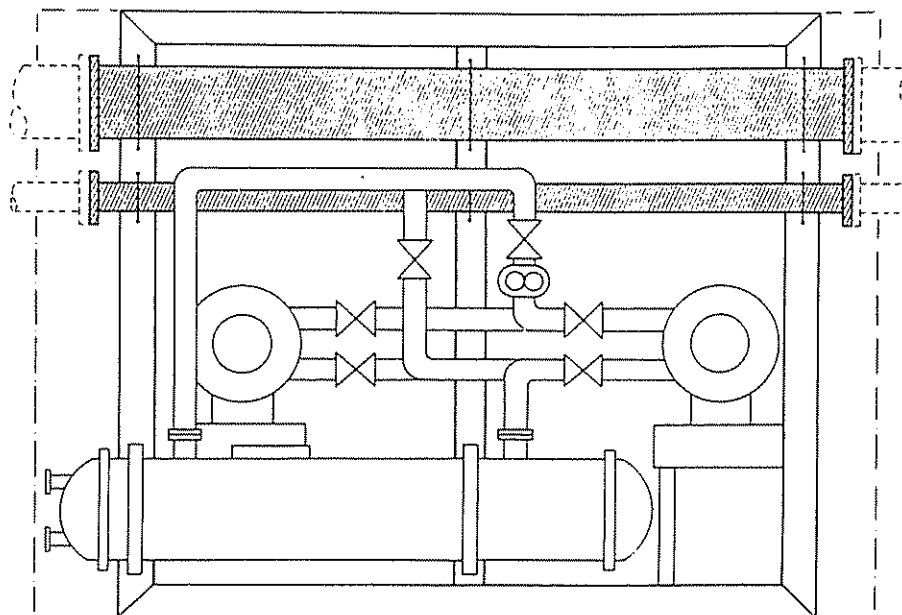


Fig. 6-45. Outfit units include pipe pieces for other systems.

ting, and painting. No one type of work proceeds without an evaluation of its cost impact on another. Sometimes additional structural weight or hull construction man-hours can result in outfit savings which more than offset the additional costs. Consequently, many hull features and block boundaries may be determined in consideration of outfit convenience. For example:

- block joints for engine room double bottom blocks are located above the grating level, so that fitting can progress in this normally congested region to the fullest extent before hull erection, and space does not have to be reserved
- as much as practical, blocks, particularly for engine room flats, are defined to be stable when upside down and when right side up (see Figure 6-48), in order to facilitate downhand outfitting on ceilings and decks
- to facilitate fitting pipe penetrations on-block, shelf plates (portions of bulkheads or decks) are provided (see Figure 6-49)
- beams with less depth are used to facilitate fitting pipe runs (see Figure 6-46), since the man-hours saved more than compensate for the thicker beam

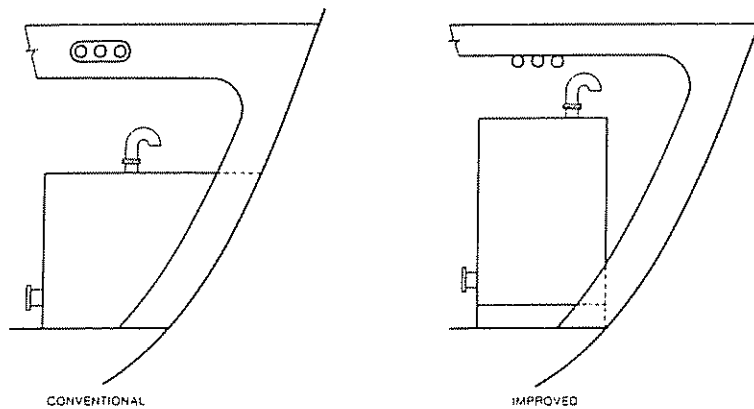


Fig 6-46 Small independent tanks built as outfit components

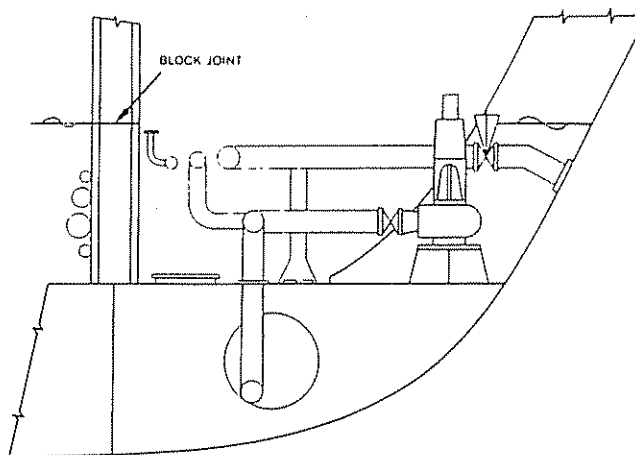


Fig 6-47 Block joints avoid interference with components.

plates required, as compared to those for beams designed only from a strength viewpoint

- trunks are provided in deckhouses for vertical pipe and electric cable runs, even at the expense of increased weight (see Figure 6-40)

3.3.5. *Overlapping Design Stages.* Theoretically, for design and production matters, each

stage should be completed before the next stage commences. As a practical measure, overlapping the various stages is essential. Successor stages necessarily start before all prerequisites are completed. The following approach may be employed to permit this shortening of the total time to complete the design cycle.

As shown in Figure 6-50, a preliminary effort for transition and work instruction design starts at C', employing incomplete infor-

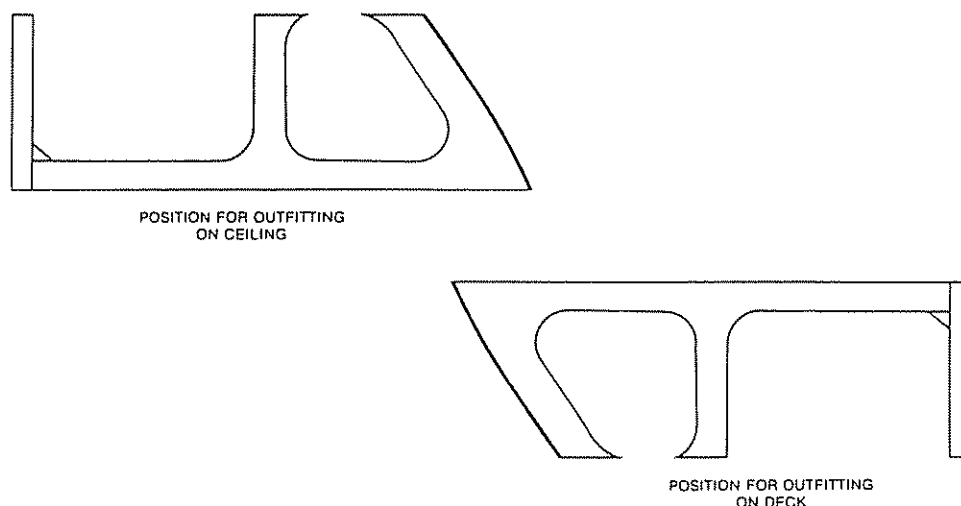


Fig 6-48. Blocks are designed to be stable right side up and upside down

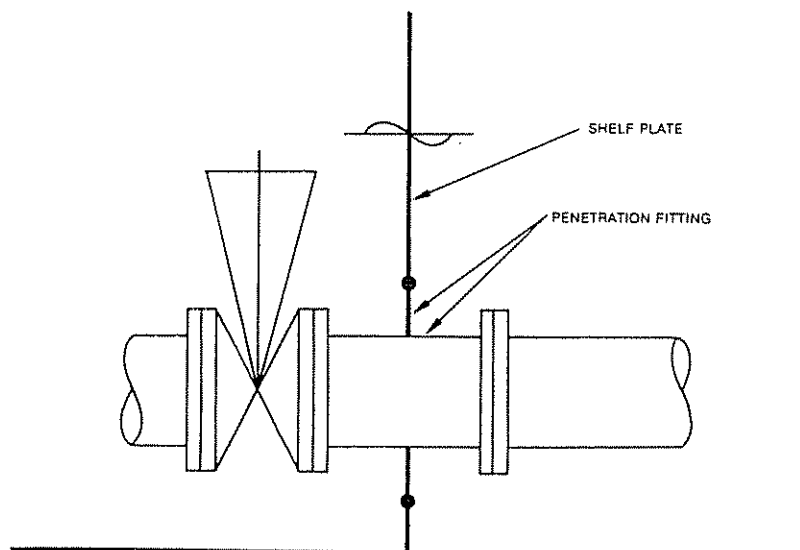


Fig. 6-49. Shelf plates facilitate pipe penetration installation.

mation from the functional design process. At C, the key plans from functional design are complete enough to undertake the major part of transition and work instruction design, because the number and extent of omissions (reservations) are not great enough to prevent substantial progress. By C" the functional design omissions are filled in, adjustments are made to adjacent concerns as necessary, and the final key plans are issued. At D', sufficient transition and work instruction design is completed, and the overlapping logic is repeated. During overlap, there is constant communication of requirements and interchange of information, as represented in the figure by the two-headed arrows. Although some rework results from the calculated risk to overlap stages, the benefit of shortening the period between contract award and delivery more than compensates for the added cost of the rework.

The overlapping logic has wide-ranging application in such areas as outfitting and structural design, delayed vendor drawings, material lists, and pallet definition.

Certain hull structural key plans are required concurrently with some outfit key plans. Cross relationships exist and there is need to progress simultaneously to minimize the duration of functional design. For exam-

ple, preparation of a mooring system plan, as shown in Figure 6-13, requires some idea of how transverse and longitudinal strength members will be arranged beneath the forecastle deck. At the same time, preparation of the hull construction plan (fore body) requires some knowledge of the major holes (penetrations) and reinforcements in deck structure needed for the mooring system. Application of overlapping logic is essential. Individuals charged with preparing the pertinent hull structural and outfit key plans meet for the purpose of reviewing drawings for a previously built similar ship and/or design module. Their objective is to preliminarily locate outfit components and structural members. Then, both plans are developed separately until enough progress has been made to justify a second coordination meeting. At that meeting, arrangements and dimensions are finalized.

Vendor drawings, such as for boilers and winches, are frequently delayed. Reasons include the sometimes extensive approval processes required. Overlapping is appropriate and consequently design development continues. Preliminary composite arrangements and fitting drawings are produced using drawings of similar vendor equipment. For this purpose, classifying and filing information about pre-

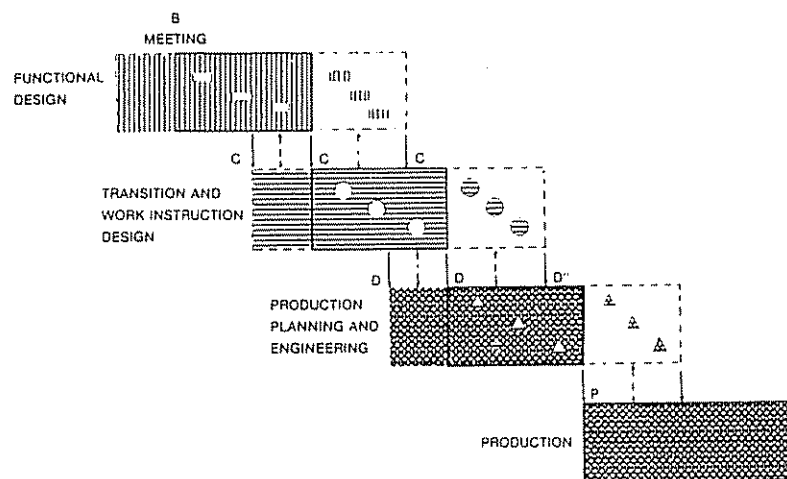


Fig 6-50. Logic for overlapping design stages

viously employed vendor equipment is very important. Accumulation of such knowledge discloses similarities and the realization of some standardization.

Overlapping logic is inherent in the techniques for defining material in MLS and MLF, as described in Parts 2.2.2. and 2.4.2., respectively. Listing all required materials on MLS during functional design by actual counts or estimates is a technique for quickly initiating procurement. Later, as material definition is refined during work instruction design, the definite quantities by pallet, obtained from MLF, are substituted for those previously obtained from MLS.

Overlapping logic is also inherent in the definition of pallets as described in Part 2.3.1. Initial coordination outlines rough pallets, the second defines the pallets, and the third finalizes them.

3.3.6. Format Standardization for Purchase Order Specifications. Materials known by many names, such as raw materials, machinery, equipment, tools, spare parts, and fabricated components, can be conveniently ordered by reference to a national or manufacturer's standard. In such cases a standard code readily substitutes for a technical description in a purchase order specification. However, for a particular item that will probably be required again, whether standard or not, it is often necessary to specify optional features that are offered by the manufacturer. For such items, a standard formal purchase order specification should be prepared (see Figure 6-51), so that a designer simply fills in blank boxes. The benefits are:

- unification of design philosophy
- clear identification of features to be checked
- fast issue
- reduction in skill levels required to prepare specifications
- ready understanding by manufacturers of what is specified

The greatest benefit is the contribution such formats make to widening the philosophy of standard material usage.

3.4. Design Changes

Because even seemingly conventional merchant ships are relatively complex, designers frequently encounter design changes. These may be due to revised requirements or to approval comments by an owner, classification society, or other regulatory body, or due to a revised build strategy or insufficient design department study and development work. The numbers of such changes can be reduced and the impact of the remainder can be minimized by specifically organized preparations and countermeasures. Changes in naval ship construction are also common, due to similar causes plus the desire to incorporate the latest technology in combat systems. In fact, an extensive system to deal with change orders is in existence and is a major consideration in naval ship construction contracts.

3.4.1. Sources. Some causes of design changes are suggested by the following:

- owner
 - different thinking and preferences
 - market changes
 - different practices
 - specialty
- classification society and other regulatory bodies
 - application of new rules and regulations
 - application of recommendations
 - different interpretations of rules and regulations
- production department
 - revised fitting stages
 - revised pipe joint locations, etc.
 - revised fitting positions of outfit components
 - revised manufacturing processes

STEAM WINDLASS		NOTE : Fill * marked items without fail.			
INSTRUCTIONS *	RULE AND GRADE	Q' TY ship set(s).			
	TYPE, CAPACITY, AND QUANTITY	CODE	SKETCH	RATE LOAD * RATED SPEED	QUANTITY
		HCEW		CHAIN DRAM t m/min	HAWSER DRAM t m/min
		WECH (SYMMETRIC)			
		HECW			
		WECH (SYMMETRIC)			
		CEHW			
		WHEC (SYMMETRIC)			
		HECHW			
	WHCEH (SYMMETRIC)				
CHAIN TYPE	mm dia., U-3 . Kenter shackle				
STOWING LENGTH OF HAWSER	Nylon, mm dia x m Wire, mm dia. x m				
AUTO-TENSION DEVICE	Yes/No DRUM TYPE Intermediate flange, Yes/No WARPING HEAD Clutch, Yes/No				
OPERATION	SPEED CONTROL	Remote, Yes/No		Operation, Manual/Hydro	
	BRAKE	CHAIN DRAM	Remote, Yes/No	Operation, Manual/Hydro	
		HAWSER DRAM	Remote, Yes/No	Operation, Manual/Hydro	
	CLUTCH	CHAIN DRAM	Remote, Yes/No	Operation, Manual/Hydro	
HAWSER DRAM		Remote, Yes/No	Operation, Manual/Hydro		
NAME PLATE	Japanese English, Metric Foot - pound				
OTHERS	Besides the above, the details of particulars, materials, accessories, spare parts tests, inspections, and painting accord with the provisions of STANDARDS OF MARINE INDUSTRIES and the followings :				
OIST.	EST	NOTICE FOR STANDARD MACHINERY APPROVED IN ADVANCE			
	B C	Fill SD No in one of this copy and return it immediately after this purchase order confirmed.			
SY	P C	SD NO. APPLICABLE			
	M C	SD-1621			
Y	C C	GUARANTEE			
	S D	Within 12 months after the date of delivery			
B SY	BID. NO.	BUYER'S NAME			
	Prepared for S No.	NOTE.			
B D	DEPARTMENT MANAGER	S NO.		JOB NO.	
	SECTION MANAGER	PURCHASE ORDER SPECIFICATION FOR STEAM WINDLASS		MAT. COST CLASS. NO. 3621(BOW)/3622(STERN)	
E O	ENGINEER-IN-CHARGE			MATERIAL CODE 362100000/362200000	
	DRAFTSMAN			DWG. NO. N3621000/N3622000	
TOTAL	FILE				
SPARE PARTS BOX NO H 103					

Fig 6-51 Standard format for purchase order specifications

- revised material availability or sources
- other groups of the design department
 - revised penetration locations for piping, ducting, etc
 - revised machinery locations
 - resolution of a design reservation
 - revision of hull structure, e.g., hole, reinforcement, carling, etc.

A number of the changes caused by other groups of the design department are the inevitable result of a calculated risk to allow each of the outfit specialty groups to simultaneously undertake functional, transition, and work instruction design. Thus, certain aspects of the design progress conditionally, pending predetermined interface coordination and meetings.

3.4.2. *Preventatives.* Figure 6-52 illustrates the thought processes applied to avoid and minimize the effects due to changes. As shown, upon receipt of an inquiry, there is research of an owner's preferences as manifested in the newest ships in the owner's fleet. This at least entails visits to such ships and, if possible, discussions with the shipbuilders having experience with a particular owner. Special attention is given to details. For example, in one such investigation, an owner's preference for unusually small tile in all wet spaces, significantly more expensive, could be discovered before contract award. However, well-developed standardization and modularization, formally included in the shipyard's practices and incorporated in proposed contract documents, remains the greatest assurance for both shipbuilder and owner of avoiding change problems which are generally costly to both.

As changes caused by an owner are often approximately half of the total encountered, shipyard design specialists participate during negotiations with an owner in order to

discuss and clarify the owner's requirements to be included in contract documents such as:

- contract specifications
- general arrangement
- midship section
- machinery arrangement
- cabin plan
- piping practices
- standard materials
- standards for statistical control, such as for accuracy
- standard surface preparation, such as for painting

If possible, the incorporation of key plans as additional contract documents will do much to avoid change encounters between an owner and a shipbuilder, and even between the diverse groups within a shipyard.

Another technique which minimizes change problems is to formally meet with the owner midway through the functional design process to offer options the shipyard has within the contract that should be discussed in the context of the owner's requirements. The decisions so made are then incorporated in key plans before submission for the owner's approval.

3.4.3. *Countermeasures.* As also shown in Figure 6-52, unavoidable changes which are large in scope, because they often have impact on more than one outfit specialty group, are assimilated during a process which starts with an intergroup meeting. The engineer in charge of the group on which a change will have greatest impact is assigned lead responsibilities for coordination and consolidation of other groups' required studies and revisions. At an intergroup meeting, the lead engineer in charge will explain the reasons for and the basic substance of the change, acquire an understanding of other groups' pertinent design progress, acquire greater knowledge of

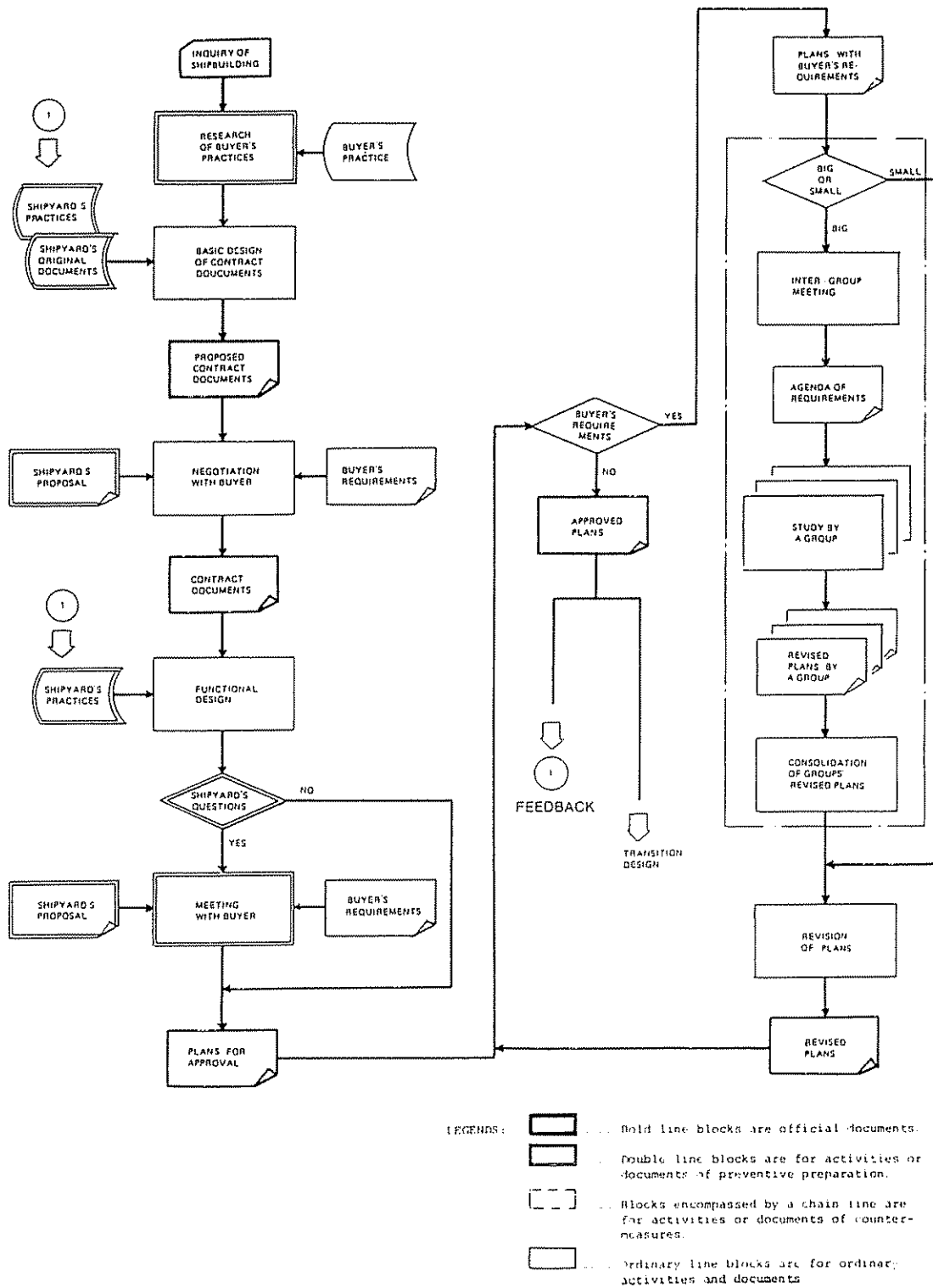


Fig. 6-52. Preventatives and countermeasures for design changes.

the effects of the change, and sometimes request that other groups stop design work wherever there is to be impact.

The study phase conducted by each concerned group typically includes preparation of sketches, examination of technical possibilities, preparation of a cost estimate, ascertaining impact on the design schedule, and presentation of findings to the engineer in charge of the group having lead responsi-

bility. The consolidation phase includes review of the concerned groups' inputs, a decision to proceed, if possible, without other than shipyard approval, a decision and submittal with cost adjustment as appropriate for owner and/or classification society approvals, and informing the concerned groups when to initiate revisions of plans. Changes which are small in scope may require some or none of the foregoing, depending on their natures.

4. CAD/CAM

The use of computers in the shipbuilding industry began in the early 1950s and has progressed steadily since that time. Used initially as accounting tools, computer applications have expanded to include many of the standard naval architectural computations. The many current or potential uses of the computer in shipyards are not all strictly covered by the CAD/CAM terminology. For example, a list of computer-aided functions could include:

- computer-aided design (CAD)
- computer-aided drafting
- computer-aided engineering (CAE)
- computer-aided manufacturing (CAM)
- computer-aided material definition
- computer-aided process planning (CAPP)

Applications of the computer in shipbuilding include:

- estimating
- design
- engineering
- drafting
- planning
- scheduling
- accounting
- purchasing
- material control
- numerically controlled (N/C) operations
- robotics

- accuracy control
- quality assurance
- inventory control
- evaluating

Additionally, the use of computer simulation and virtual reality is becoming more common in design and manufacturing applications and may also find increasing use in the shipbuilding industry. Consequently, the term CAD/CAM must be expanded. The resulting process is often referred to as computer-integrated manufacturing (CIM)

A CAD/CAM or CIM system is a combination of hardware and software. The ultimate goal of such a system is depicted in Figure 6-53. [7] The user interacts with the computer via a graphics terminal, designing and manufacturing a part from start to finish, while coordinating with the complete shipbuilding system. Information from the design and manufacturing functions is available and transmitted via a common central data base, which may include a complete 3-D product model. Applying the CAD features, the designer may construct a geometric model, perform required engineering analyses, perform kinematic studies, and produce plans and work instructions. Employing the CAM functions, the user creates N/C instructions, controls robots, performs process planning for the entire construction process, and coordinates with a shipyard management system. Pur-

chasing and material control are also coordinated through the common data base. While many systems have the CAD functions interfaced, with the exception of some N/C programming capability, most systems do not have CAM interfaces. The major problem facing shipbuilders in the application of CIM is the lack of a unified shipbuilding data base that provides the capability of interfacing with all the applications mentioned above.

4.1. Hardware and Software

CAD/CAM systems have been developed in two ways: hardware alone or hardware/software combinations. While numerous systems of both types are available, there is no industry standard. Computer hardware changes rapidly and computer systems evolve based on the latest hardware availability. There

are no standard hardware requirements, but typical systems may include mainframe-based systems with terminals and/or independent workstations or personal computers (PC), often linked by local area networks (LAN). In addition to plotter and printer outputs, data outputs such as N/C tapes and direct machine control information may be used. Considerable effort has been expended and progress made toward the development of standards for the direct electronic interchange of data. The standards include the Initial Graphics Exchange Specification (IGES) for the transfer of graphic data, and the Standard for the Exchange of Product Data (STEP), a more robust product data exchange standard. Programs in the United States and Europe are expanding data exchange standards availability and application. [8, 9, 10]

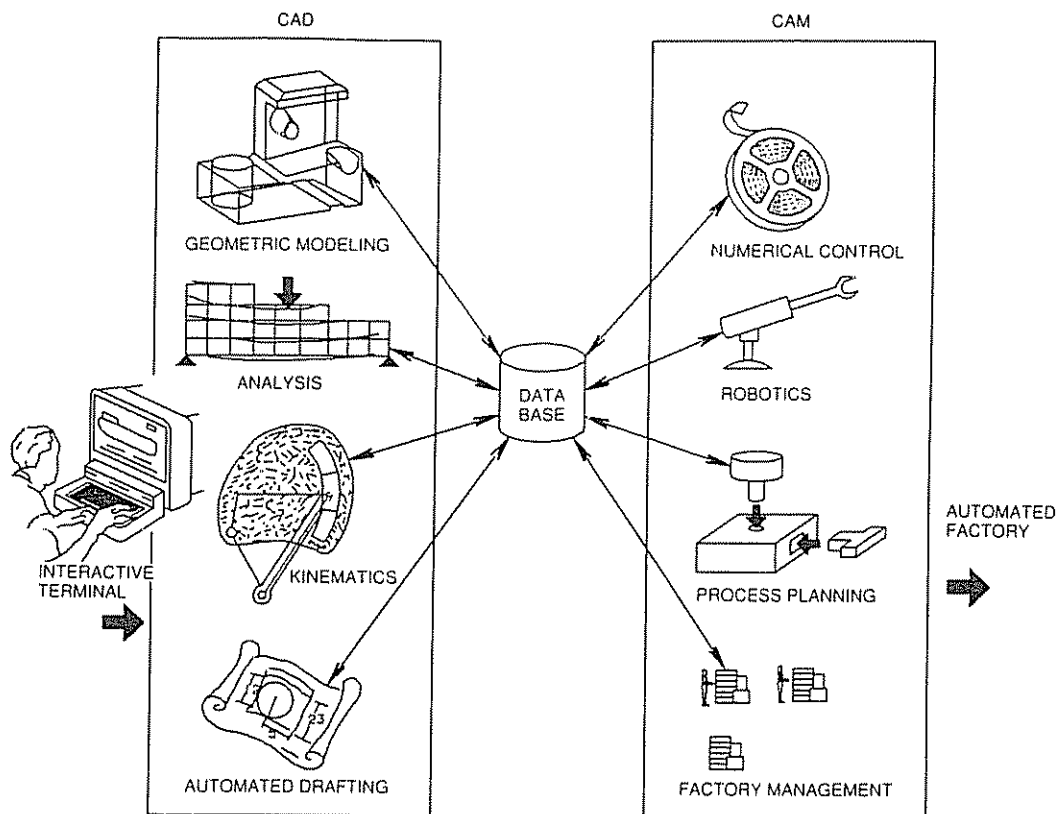


Fig 6-53 An integrated CAD/CAM system.

There are many integrated ship design CAD/CAM programs. The most commonly used are AutoSHIP (Canada), FORAN (Spain), HICADEC (Japan and Denmark), HULLTECH (England), NAVSEA CAD-2 (U.S.A.), NAPA (Finland), and TRIBON (Sweden and Germany). AutoSHIP, developed by Coastdesign, is aimed at small and medium-sized shipyards. FORAN is licensed for use by more than 100 shipyards in 19 countries. It is developed by Senemar. HICADEC was originally developed in Japan by Hitachi Zosen. Additional development, including production management and robotic programming has been added to the system by Odense Steel Shipyard of Denmark. HULLTECH is the follow-on product to the BRITSHIPS system, currently developed by the BMT Group. NAVSEA CAD-2 is an integrated system developed by Intergraph initially to support design, construction, maintenance, overhaul, and repair of U.S. Navy ships. NAPA is the latest version of the system developed initially by the Wartsila Corporation, now updated and maintained by a separate company. TRIBON is the result of the integration of three other programs, AUTOKON, STEERBEAR and SCHIFFKO. It is developed and maintained by Kockums Computer Systems (KCS) and is the most widely used system in large shipyards worldwide [11].

These and other computer systems continue to progress. Most have direct NC links for functions such as lofting and cutting of plate and stiffeners. Some also provide additional capabilities, such as pin jig setting, N/C bending of plate, stiffeners, and pipe, and robotic programming. Most require the development of a 3-D product model, although basic design, especially as a part of marketing, may still be done using simpler 2-D models. Development of an integrated data base remains a high priority for the eventual coordinated application of CAD/CAM or CIM systems in shipbuilding. Information required in the data base includes:

- numerical data on past designs
- geometric data on past designs, e.g., hull forms
- weight and space scaling laws
- systems and equipment
- structural design data
- resistance and propulsion data
- engine performance data
- sea spectra
- cost data
- typical block plans
- typical outfit units
- shipyard (or national) standards
- material lists (MLS, MLF, MLC, MLP)

4.2. CAD Outputs

The eventual outputs of a CAD system that is part of an integrated CAD/CAM system will be both hard copy materials, including plans, lists, and work instructions, and computer data transmitted to workstations, such as N/C burners, pipe-bending machines, and robots. Systems that completely bypass the hard copy stage and simply transmit data to be stored and retrieved by computers on the ship, in the owner's office, at the classification society and regulatory body offices, and at the machines or workstations within the shipyard are under development. Current systems employ hard copy outputs that are used to perform the necessary functions. As described in Section 2.5., many shipyards employ the computer capability housed within the mold loft to produce the various types of outputs required.

Application of a CAD/CAM system permits the evaluation of additional design options as well as consideration of alternate build strategies. Computer-generated plans, lists, and work instructions [12] may be used for the various design cycle stages as well as shipbuilding management functions, including:

- general arrangements; basic design
- key plans; functional design (see Figure 6-54)

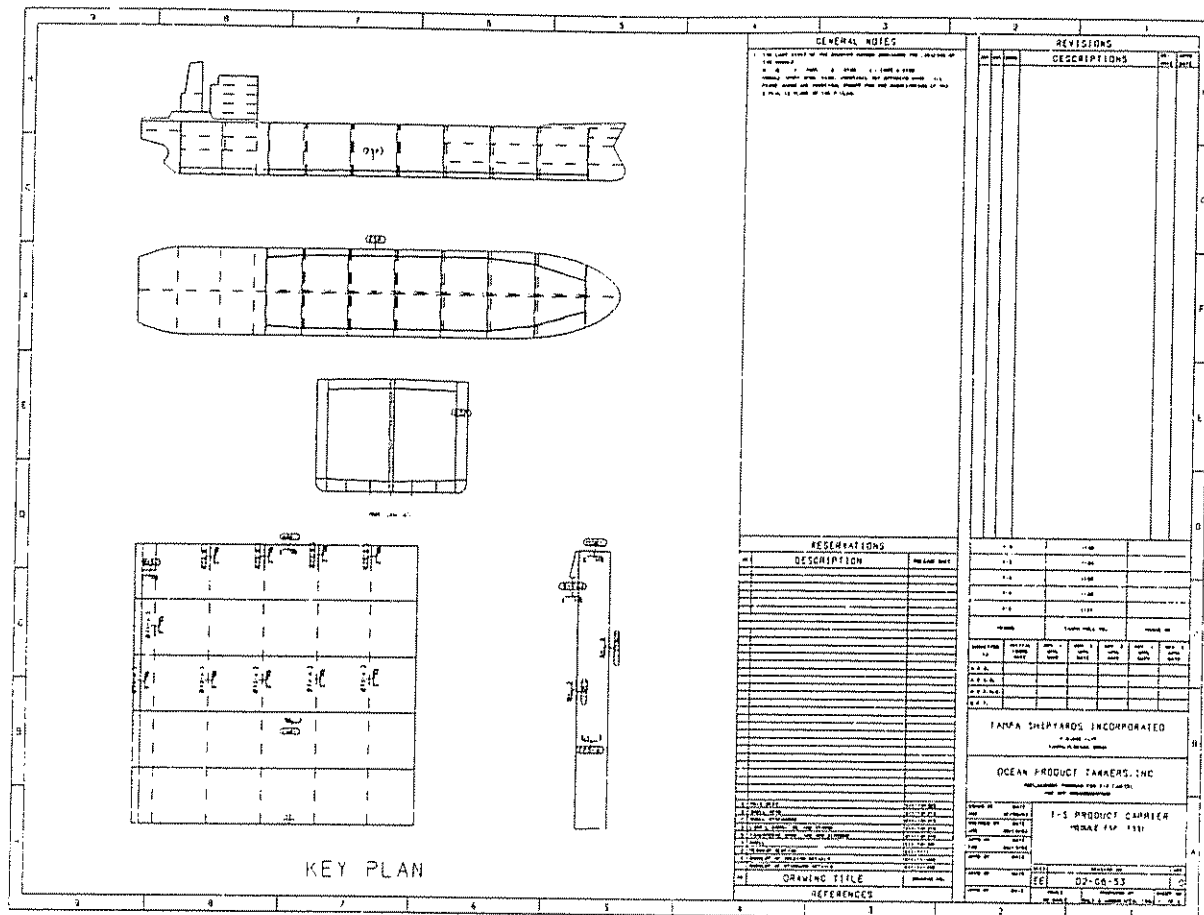


Fig 6-54 CAD-generated key plan

- yard plans; transition design
- work instructions; work instruction design (see Figure 6-55)
- schedule reviews (see Figure 6-56)
- material lists
- purchase lists

Many other types of computer-generated outputs can be used

4.3. CAD/CAM Potential

The ultimate goal of a CAD/CAM system is improvement in shipbuilding productivity. Among the advantages of such a system are:

- the ability to produce concept and feasibility ship design studies more

quickly and accurately than by conventional methods

- the ability to rapidly evaluate design options and to optimize required features
- the reliance on a proven, coherent data base, and hence the ability to perform design calculations with confidence
- the ability to assemble and "lock-in" successful design experience and procedures
- the ability to add attractive design solutions to augment the data base for future use
- the ability to interface with computer graphics

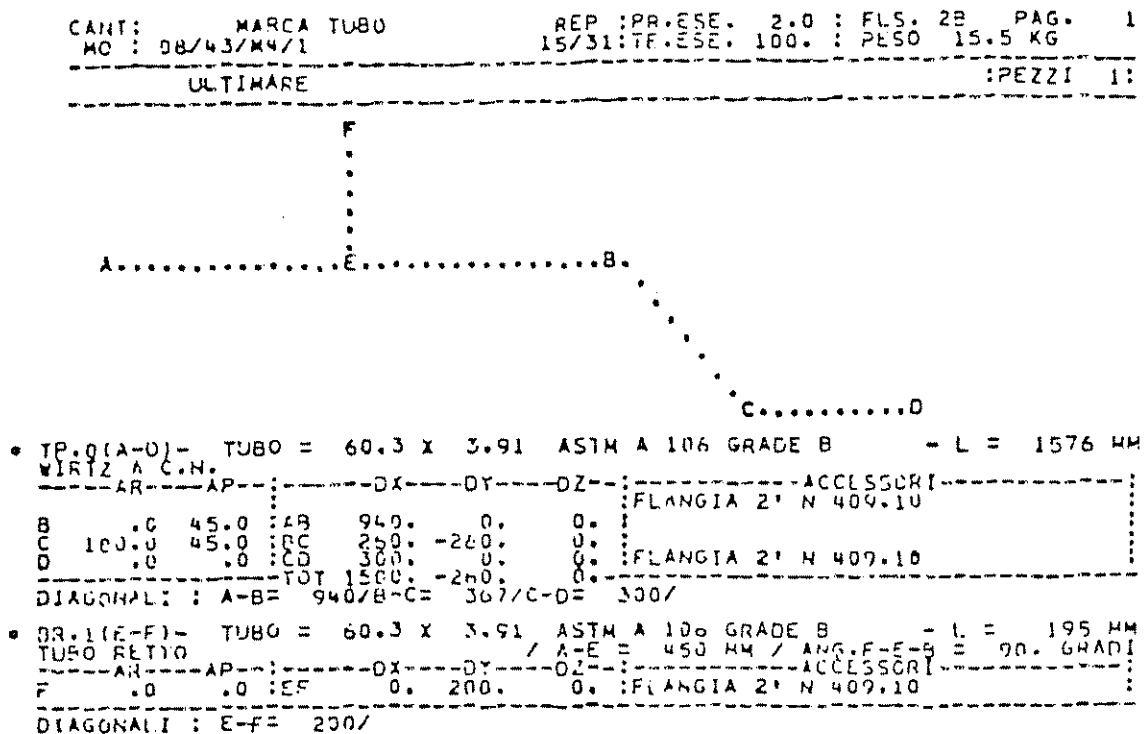


Fig. 6-55 CAD-generated work instruction.

- the ability to transfer data in digital form to shipyard design offices and manufacturing facilities
- the ability to establish and employ shipyard standards
- the ability to assemble and "lock-in" successful build strategies and procedures

With these added capabilities, support for production efforts by other shipyard organizations, such as design, engineering, purchasing, and material control, is enhanced (see Figure 6-57). The coordinated system will lead to simplification of all aspects of the design and production process (see Figure 6-58). [12]

5. Models

The design cycle described in Section 2 has as a major feature the transition from system to zone during transition design. The composites produced during this design stage are critically important. Since they reflect the way the ship will be built, the composites directly affect the productivity of the shipbuilding project. They also are the basis upon which engineers performing work instruction design do their work. The use of design models has proven to be an effective technique for

improving transition and work instruction design. The models also provide significant benefits to production, planning, and scheduling personnel.

Design models, formerly done as full-scale mock-ups or as scaled plastic models,[13] permit design to be done in three dimensions, rather than on the more traditional two-dimensional drawings. The benefits of visualization of the space and the items to be included within the space are apparent. Mod-

SCHEDULE REVIEW REPORT									
08050		SCHED# C10015-02 OUTFITTING EXXON					WEEK ENDING 6/28/81		
DRAWING	ITEM	WEEKLY HRS. HRS 8/4 INITIAL ISSUE	EQUIV. MANDAYS	WEEKLY O.T. 8/4 INITIAL ISSUE	EQUIV. O.T. MANDAYS	WEEKLY HRS. AFTER INITIAL ISSUE	EQUIV. MANDAYS	WEEKLY O.T. AFTER INITIAL ISSUE	EQUIV. O.T. MANDAYS
12	0511 01	9.3	1.16						
16	0201 01	2.0	.25						
16	0203 01	11.0	1.37						
16	0402B 01	23.5	2.93						
16	0403 01	15.7	1.96						
19	0101 01	40.0	5.00						
34	0101 01	22.0	2.75						
91	0101 01	8.9	1.11						
TOTALS		132.4	3.31						
TOTAL # OF DRAWINGS		8							
TOTAL # OF DRAWINGS WITH NO HOURS SPENT		0							

Fig 6-56. CAD-generated schedule review

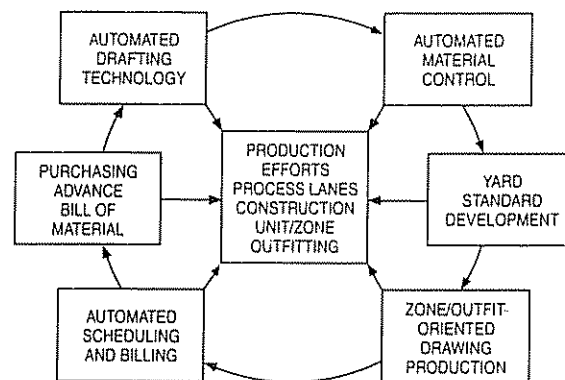


Fig 6-57. CAD/CAM future

ern computer systems now permit the use of 3-D solid computer models for design. Design using inclusive virtual reality may also be employed to improve both the design and the productivity of the production effort.

The benefits of design models may be summarized as follows:

- An arrangement existing in three dimensions facilitates group thinking

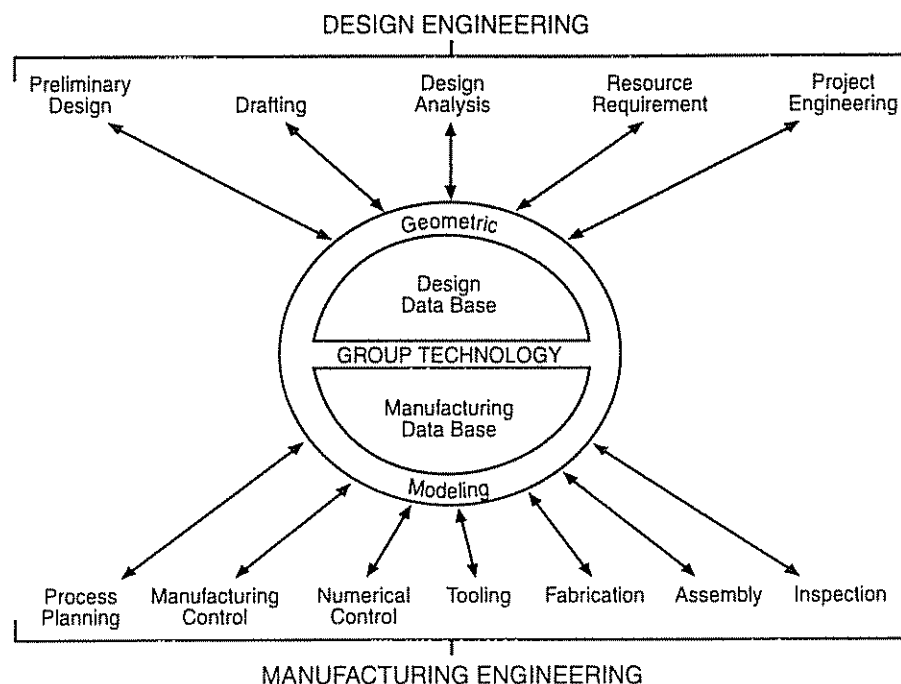


Fig 6-58 CAD/CAM network.

and checking, thus minimizing errors in design (interferences) and rework in production.

- Alternatives in design and production are more easily evaluated.
- The model permits better use of less well trained personnel in design, planning, and production.
- Build strategy communications between production, production engineers, and designers are enhanced.
- Problem resolution is enhanced.
- Design progress is readily apparent.
- Communications with owners concerning vessel operations, requirements for maintenance and overhaul, and other matters are enhanced and are more timely.
- Communications with regulators are similarly enhanced.
- The model is an effective training tool for people in design, planning, production, and production control.

- A design model is a data bank, permitting retrieval of prior practice and use in negotiations with prospective customers.

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PLANNING, SCHEDULING, AND PRODUCTION CONTROL

1. Introduction

The management of any large industrial project, such as new ship construction and ship repair, overhaul, or conversion, requires the use of the related techniques of planning, scheduling, and production control. The productivity of the project is dependent on the coordination of material, manpower, facilities, capital, and information. Managing these resources is the key to efficient production.

Figure 7-1 shows the basic management cycle. The planning phase of a project is the listing of all jobs that must be performed in order to complete the project. As part of planning, any required ordering of the jobs must be determined, as well as gross requirements for material, manpower, and facilities. Additionally, estimates of costs and job durations are developed as a part of the planning process. [1]

Scheduling is the laying-out of the actual time order in which jobs are to be performed in order to complete the project. Material and manpower requirements needed at each stage of production are determined, as well as start and finish times for each job.

Production control is the monitoring of the difference between actual and scheduled performance. The analysis of and response to this difference is the primary aspect of pro-

duction control. It is often considered to be the "underlying managerial function." Production control occurs during the execution stage of the management cycle.

1.1. Planning and Production Organizations

The type, amount, and complexity of required planning is closely related to the type of production organization involved. Figure 5-1 (see Chapter V) showed some general relationships between production organizations and planning. The importance of planning and scheduling to an industrial organization based on the principles of group technology was described. In particular, planning and scheduling are critical to a successful group technology shipbuilding system. This highly detailed, complex planning and scheduling, which is required to productively manage the shipbuilding process, is an overall coordinating function and controls the system.

1.2. Integration with Other Shipbuilding Functions

Planning, scheduling, and production control must be totally integrated with other shipbuilding functions in order to take advantage of the application of group technology. Since

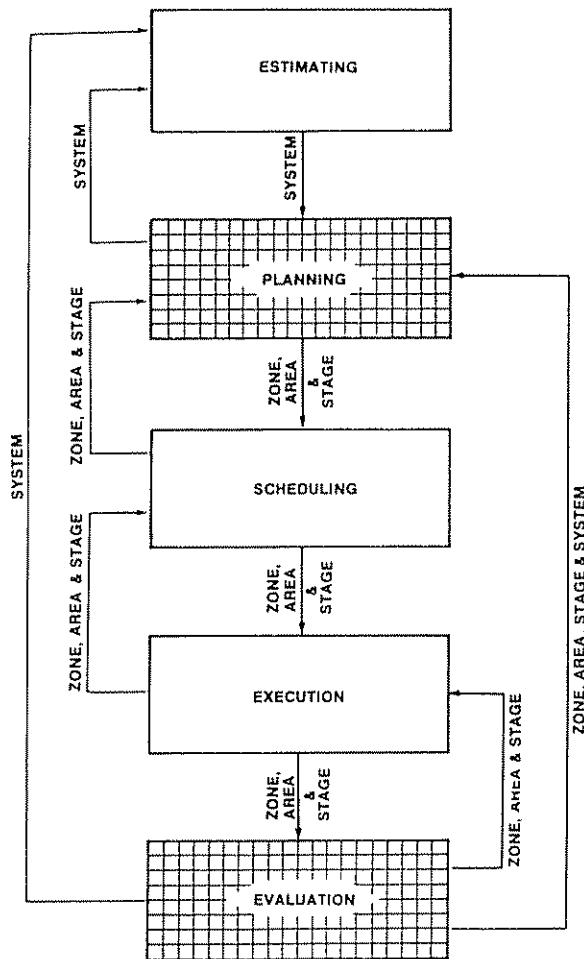


Fig 7-1. The management cycle.

the product-oriented work breakdown structure is concerned with work flow organized to obtain the benefits of mass production, wherever possible, planning becomes the medium through which this build strategy is adopted and transmitted to production. The build strategy considers the shipyard's capabilities, standards, and preferences (see Figure 7-2), and combines those with the contract or customer requirements. It is reflected in the block plan and key date master schedule, including material requirement dates. The build strategy can involve preliminary and detailed stages. It provides input to design and includes strategic, tactical, and detailed

production engineering and process analysis (see Figure 7-3). [2]

Based on the build strategy, planning and scheduling functions provide the design organization with a description of how to build the vessel, in what order to erect the vessel, and within what time frame. Design and engineering schedules can then be established to permit timely development of information concerning what to build and what to procure. Based on this and the scheduling information, material procurement can be undertaken to provide the necessary materials at the required times, just in time if possible. Production control monitors the actual performance of the production work force and compares it to planned and scheduled performance. Strategies to handle these differences can be developed and implemented as required.

Consequently, the functions of planning, scheduling, and production control are directly related to production, design, and engineering; material procurement and control; and estimating. These functions therefore permeate the entire shipbuilding management cycle.

1.3. Networks

In defining planning and scheduling, the need to identify independent jobs or activities and an order of precedence for these jobs was described. These data represent the prerequisites for employing the primary techniques of the Critical Path Method (CPM) or the Program Evaluation and Review Technique (PERT). Both are based on networks. Although it is rare in shipbuilding to actually employ formal CPM or PERT algorithms, networking of subsets of the total project is often used to aid in planning and scheduling.

Networks are formed by connecting events, represented by nodes, with activities, represented by arrows. Events occur at the start or completion of an activity. Consequently, they involve no passage of time. Activities corre-

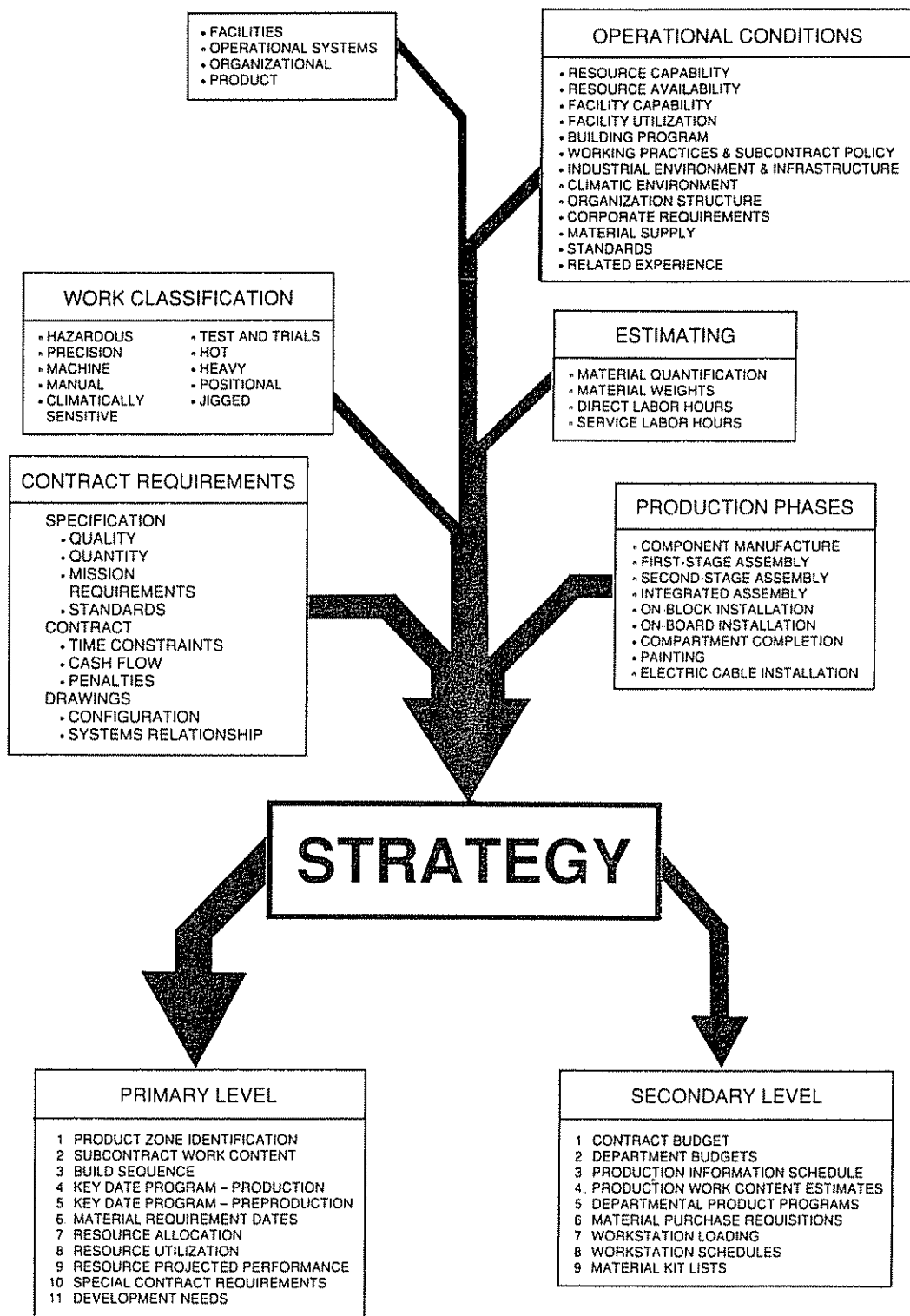


Fig 7-2 Build strategy process

Table 7-1. Example of data required to develop a network

Activity Identification	Activity Description	Immediate Predecessors	Duration (Days)
a	Determining steel plate order	—	3
b	Shipping steel plate to a shipyard	a	10
c	Preparing N/C tapes for cutting plate	—	7
d	Cutting parts for subassembly 1	b, c	1
e	Cutting parts for subassembly 2	b, c	1
f	Assembling subassembly 1	d	5
g	Assembling subassembly 2	e	5
h	Transporting subassembly 1 to block assembly site	f	1
i	Transporting subassembly 2 to block assembly site	g	1
j	Assembling block 1-2	h, i	3

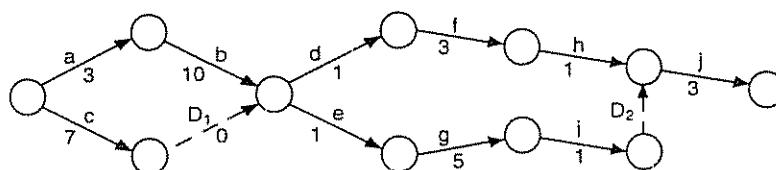


Fig 7-4. Network example.

g, i, D₂, j, is the critical path, with a project duration of 23 days.

The use of networks, with variations on job duration options, can provide planning and scheduling with quantitative decision-making information. PERT is used to consider activity duration uncertainties and CPM is used to trade off total cost and the shortening of individual activities. Further extensions of these techniques exist to evaluate resource limitations, multiple shipbuilding programs, etc. A primary weakness of network management systems such as PERT and CPM is the cost in time and effort required to maintain the network. Since resource management is dynamic, the network must be kept current in order to be effective. This requires constant feedback.

Computer algorithms and effective management information systems are essential to facilitate network creation, network updating, and computations for complex projects like shipbuilding. Advanced stochastic network simulation management systems have been developed to better manage risk and uncertainty. These are not generally used throughout the industry, although they are being applied in some naval shipyards for complex overhauls. The use of computer-integrated manufacturing systems is an effective way to deal with the computational complexity associated with network data generation and feedback. Considerable activity to develop and implement such systems is underway, and some shipyards have parts of such integrated computer systems in place.

1.4 Activity Durations

Estimating activity durations is a critical aspect of planning and scheduling. Two primary techniques may be employed: productivity indices based on historical data, and engineered labor standards.

1.4.1 Productivity Indices Productivity indices are determined by collecting man-hour expenditures for workstations operating within a specific problem area at each manufacturing level. Statistical analysis of historical data is used to determine the best correlation between a problem area and an associated index. Figure 7-5 provides typical examples of productivity indices presented by problem area and manufacturing level. Although the actual values of the indices would be shipyard specific, their general form should be applicable to many shipyards. [3]

1.4.2 Engineered Labor Standards In the absence of historical data by problem area, es-

timates of activity durations can be generated by the use of engineered labor standards. These standards are based on theoretical determinations of the actual time it would take to perform all the movements associated with doing a job (the process time) and then adding a factor to account for time spent not actually doing the job (the nonprocess time). Extensive data bases of process times have been developed and may be used to determine process time for any shipbuilding activity, such as fitting, grinding, welding, and bending. Nonprocess time must be determined from historical data. This includes personal time, waiting for material, reading work instructions, equipment breakdown, and waiting for cranes. Typical nonprocess time factors can be determined and used in conjunction with theoretical process time data to estimate actual activity durations. Once historical data by problem area is available, its use would preclude the need for engineered labor standards.

2. Planning Overview

Shipyard planning can be viewed from two perspectives: the total yard overview and individual construction or repair jobs. The yard overview is essentially the sum of all individual projects, but it involves longer-term considerations, including market forecasting, work load forecasting, employment forecasting, and facility improvement forecasting. Individual project planning begins with the development of a build strategy and then proceeds to greater levels of detail for a specific project.

Some degree of planning is inherently incorporated in each shipyard function such as design, material control, industrial relations, and quality assurance. By organizing some of these functions and subfunctions in terms of common processes, the formal planning, which provides the framework for communication, can be simplified. As illustrated

in Figure 7-6, the planning function itself is concerned with different levels of detail to support the production process. At the top, plans concern themselves with long-range business considerations, such as market analyses, facilities, and financing, and contain a great deal of uncertainty. Long-range plans create a framework for the development of near-term plans. These concern themselves more with contracts in hand and probable business. Short- and long-range plans are the bases for assigning the resources required to accomplish current and anticipated work and provide management with basic guidelines needed for business decisions. [3]

2.1 Shipyard Planning Overview

Top-level management is generally responsible for developing a corporate plan. This plan typically indicates company goals projected

				MANPOWER EXPENDITURE INDEX	PRODUCTION PROGRESS INDEX	PRODUCTIVITY INDEX
TYPE OF WORK	HULL CONSTRUCTION	FAB	PART	MHRS/UT	FABRICATED WT/UT	MHRS/FABRICATED WT
			SUB- ASSEM	.	SUBASSEMBLY WT/UT SUBASSEMBLY Wp/UT	MHRS/SUBASSEMBLY WT SUBASSEMBLY Wp/MHR
		ASSEMBLY	ASSEM	.	ASSEMBLY WT/UT ASSEMBLY Wp/UT	MHRS/ASSEMBLY WT ASSEMBLY Wp/MHR
			ERECT	.	ERECTED WT/UT ERECTED Wp/UT	MHRS/ERECTED WT ERECTED Wp/MHR
	OUTFITTING	FAB	PPFM	.	MANUFACTURED WT/UT MANUFACTURED PIECES/UT	MHRS/MANUFACTURED WT MHRS/MANUFACTURED PIECES
			DECK	.	PARAMETRIC-COMPONENT WT/UT	MHRS/PARAMETRIC-COMPONENT WT
		ASSEMBLY	MACH	.	PARAMETRIC-COMPONENT WT/UT	MHRS/PARAMETRIC-COMPONENT WT
			ACCOM	.	PARAMETRIC-COMPONENT WT/UT	MHRS/PARAMETRIC-COMPONENT WT
			ELECT	.	LAID CABLE LENGTH/UT CONNECTED CABLE PIECES/UT PARAMETRIC-COMPONENT WT/UT	MHRS/LAID CABLE LENGTH MHRS/CONNECTED CABLE PIECES MHRS/PARAMETRIC-COMPONENT WT
	PAINT	ASSEM	—	.	COATED SQUARE METERS/UT	MHRS/COATED SQUARE METER

MHR: man-hour; UT: unit time; WT: weight; Wp: a parametric length for welding which takes into account weld size, type, and position

Fig. 7-5. Productivity indices.

on current conditions to some time in the future. Five-year corporate plans are common. They incorporate market analysis and shipyard capability analysis, including labor and capital (facility) requirements. Market research techniques are used to predict the range of products (ships) and therefore the type of projects the shipyard will seek. This information must then be matched with the shipyard's facilities and resources.

The long-range marketing plan should address typical work loads for traditional shipyard work, including new construction and repair. It should stress the primary markets to be pursued, such as Navy versus merchant ships, large versus small vessels, etc. Other factors that can also be considered are non-

traditional projects, including offshore structures and nonmarine work. Based on the projected market, a review of long-term facility and labor needs should be undertaken. Typical parameters, such as actual and projected throughputs in tons per square foot, dry dock utilization, and building site needs, can be used to assess facility improvement needs.

Planning should also address work flow for current work and proposed new bids to serve as a guide for yard capabilities in the face of actual and projected contracts. Figure 7-7, indicating a period of interrupted work flow, should be avoided. Figure 7-8 shows a better planned, smooth work flow, resulting from the blending of new contracts with existing contracts. Such a plan provides guid-

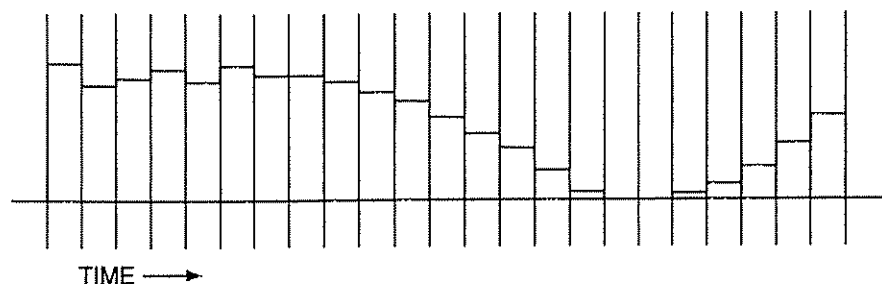


Fig. 7-7. Interrupted work flow.

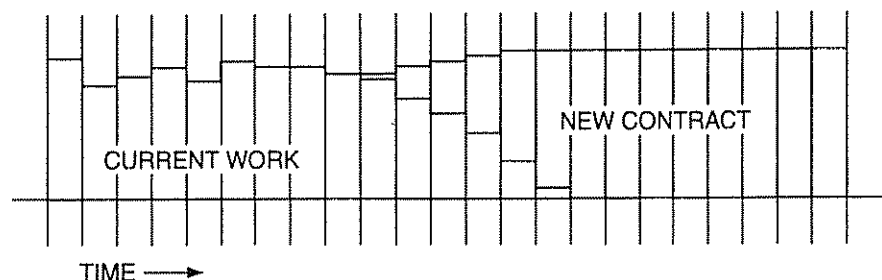


Fig. 7-8. Level work flow.

- develop design details zone by zone, regardless of systems represented, in a sequence which anticipates how each ship will be assembled

At the same time, there will be requirements for standardizing and modularizing designers' contributions to pallets. Through such efforts, part of a diagram, the corresponding portion of a composite, and the pertinent MLF can be used as is or adapted for use on future ships of different types and sizes. This reuse of previously performed design work will ultimately reduce the design workload.

2.2.1. General Planning. Ships of various types and sizes have many similarities. The degrees of sameness are particularly evident when comparisons are made in the context of zone/problem area/stage classifications. For example, many detail design differences can be accommodated without changing the zone/problem area/stage classifications of a pallet. Thus, pallets should be general enough to be adopted

or adapted for successive ships. That is, information and resources needed to perform the work associated with many pallets should be sufficiently standardized and modularized so that they can be effectively employed without changing the build strategy.

2.2.2. Precontract and Contract Planning. During contract negotiations, particular attention is given to unique aspects of the owner's requirements. As much as possible, pertinent technical matters are negotiated and incorporated in contracts. The extent of each effort that is performed before contract award depends on the uniqueness and complexity of a proposed ship and a shipbuilder's prior experiences with an owner. Potentially troublesome items include special coatings, special regulatory requirements, and unique machinery, equipment, and fixtures.

A problem confronting shipbuilding managers is how to get production people involved in basic design. One method is the use of one or two production engineers in each

shop and a formal, basic planning effort which is implemented simultaneously with basic design. Similarly, designers are required to participate in planning new facilities, because such installations, particularly for ships not built before, can affect the build strategies which must be incorporated in design end products.

During basic planning, production engineers predefine blocks. Guidance includes a proposed general arrangement, midship section, machinery arrangement, etc., for a contemplated ship, as well as limitations or other conditions which relate to the effectiveness of a particular shipyard. Such considerations include the need to:

- define blocks of maximum size and weight permitted by the shipyard's assembly and erection facilities
- minimize the number of blocks, if necessary by joining blocks which are sized to facilitate assembly into grand blocks in order to exploit a large-capacity crane at an erection site
- identify assembly and erection processes consistent with safety and the need for block accuracy and rigidity
- minimize scaffolding, lifting, turn-overs, etc
- identify blocks which can be used as patterns for other blocks in parallel midbody
- identify preliminary zone, problem area, and stage classifications for organizing work flows and, insofar as possible, equalizing the content of work packages for block assembly, subassembly, and parts fabrication

Additionally, block predefinition should consider how to:

- fit outfit components in cargo compartments
- install machinery and fit other components in the engine room

- arrange deck machinery, mooring fittings, etc.
- perform as much painting as possible before hull erection

Assessment of the efficiency of block assembly processes in terms of durations, required resources, required accuracy, and quality of work circumstances requires the following to be evaluated collectively:

- determinations of outfitting on-block or on-grand block
- ease of outfitting and painting processes
- avoidance of damage to painted surfaces and to fittings when turning over or otherwise handling blocks

Inasmuch as an erection master schedule must ultimately control sequenced durations for mold loft, parts fabrication, subassembly, assembly, and erection work, an integrated schedule must control all of the foregoing plus durations, appropriately interspaced, for outfitting and painting stages. [5]

2.2.3 Design Scheduling. Scheduling objectives for design and material definition, as shown in Figure 7-9, [6] are:

- drawing issue timing commensurate with material lead times and production schedules
- design man-hour control commensurate with a man-hour budget
- material quantity control commensurate with a material budget

A shipbuilding master schedule provides dates for fabrication start, keel laying, launching, and delivery for all ships contracted and/or expected to be built during some reasonable period (see Figure 7-10). [7]

As shown in Figure 7-11, a design department master schedule is derived from the shipbuilding master schedule and is the control mechanism for a sequence of other design

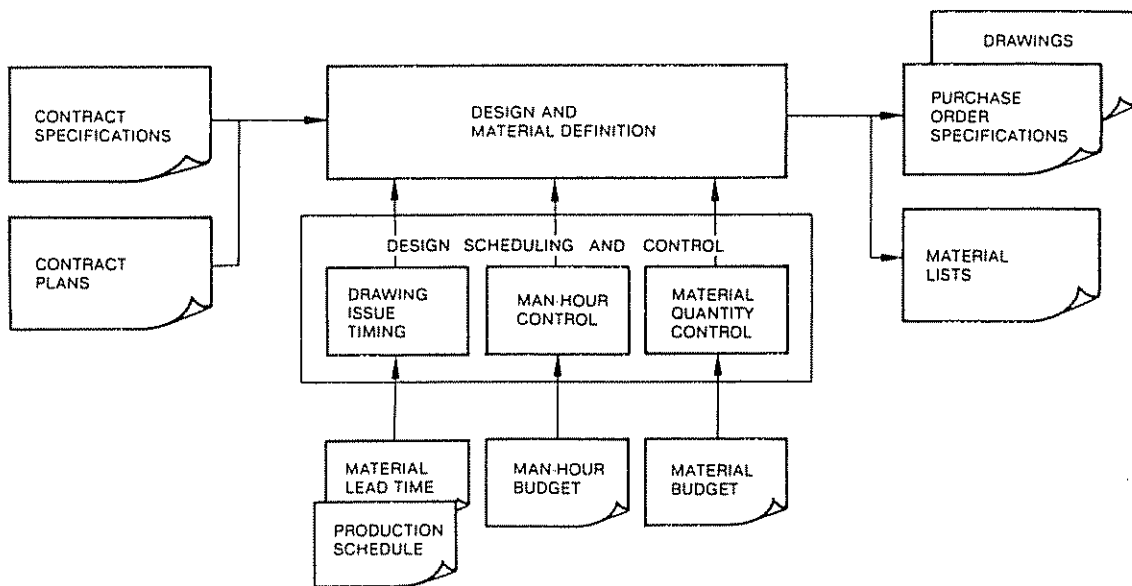
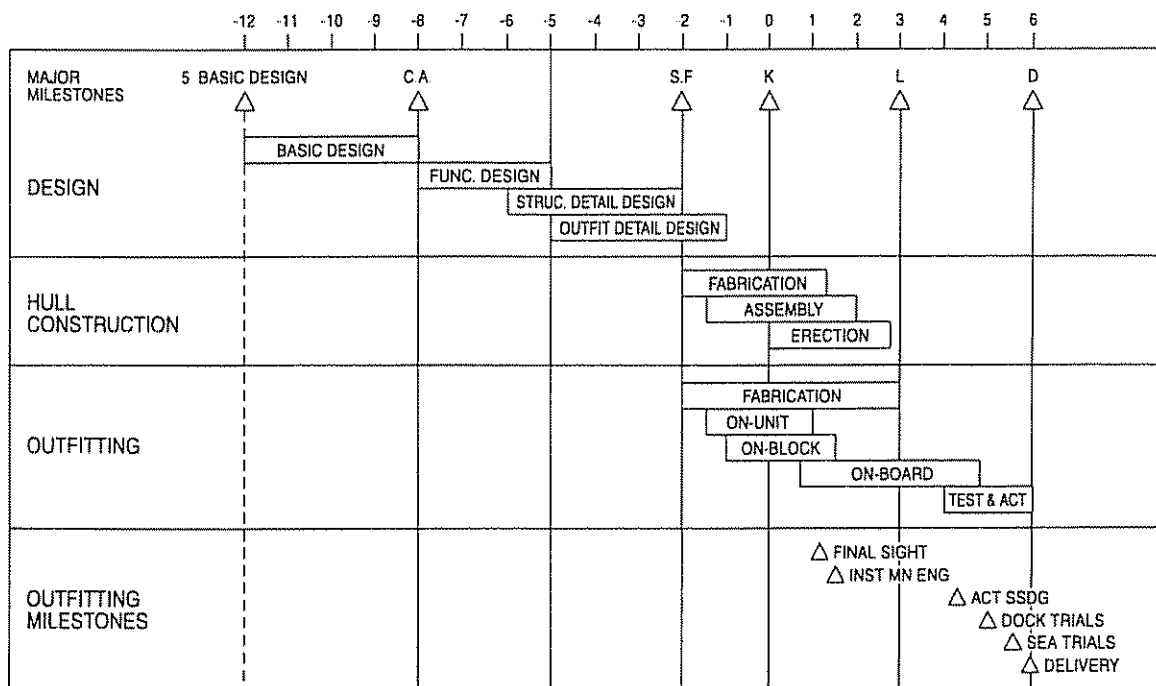


Fig 7-9. Scheduling objectives for design and material definition.



NOTES: Typical with minor adjustments for a nonstandard cargo, bulk, container, or RO/RO ship

Fig 7-10 Shipbuilding master schedule

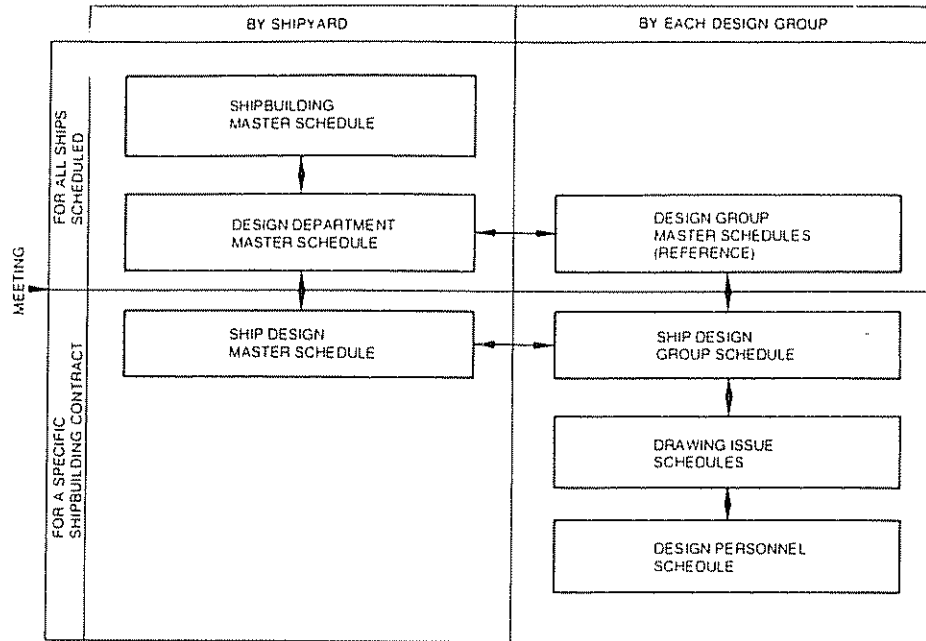


Fig 7-11 Design scheduling sequence

schedules. These control the design work for specific ships and the efforts of the outfit specialty design groups.

Design Department Master Schedule A useful format for a design department master schedule is illustrated in Figure 7-12. All ships in the order book are addressed plus those for which orders are expected. The format is a combination of:

- a Gantt chart representation of the shipbuilding master schedule showing keel laying, launching, and delivery dates for each ship
- S-curves, each of which shows the accumulated design man-hours estimated for each ship (see Chapter II for discussion of shipbuilding S-curves)
- a plot of the total estimated design man-hours required by month

The latter is guidance for leveling and balancing the design work load. It also serves to indicate if and when additional design projects

can be undertaken and to predict the need for overtime and/or subcontractor man-hours.

To support preparation of a useful design department master schedule, historical data files must be accurately maintained. These consist of design man-hours by typical ship, by ship type/deadweight (design man-hours by ship are adjusted to account for atypical features), and design man-hours available by month.

Design Group Master Schedules. Within controls invoked by the design department master schedule and using the same logic and format, each of the outfit specialty groups prepares a design group master schedule. This presentation enables a group manager to predict manpower shortages or surpluses. With such guidance, plans are made for manpower transfers, overtime, and/or subcontracting in order to level and balance the work load imposed on each group by the design requirements for all ships.

The design group master schedules, together with the design department master

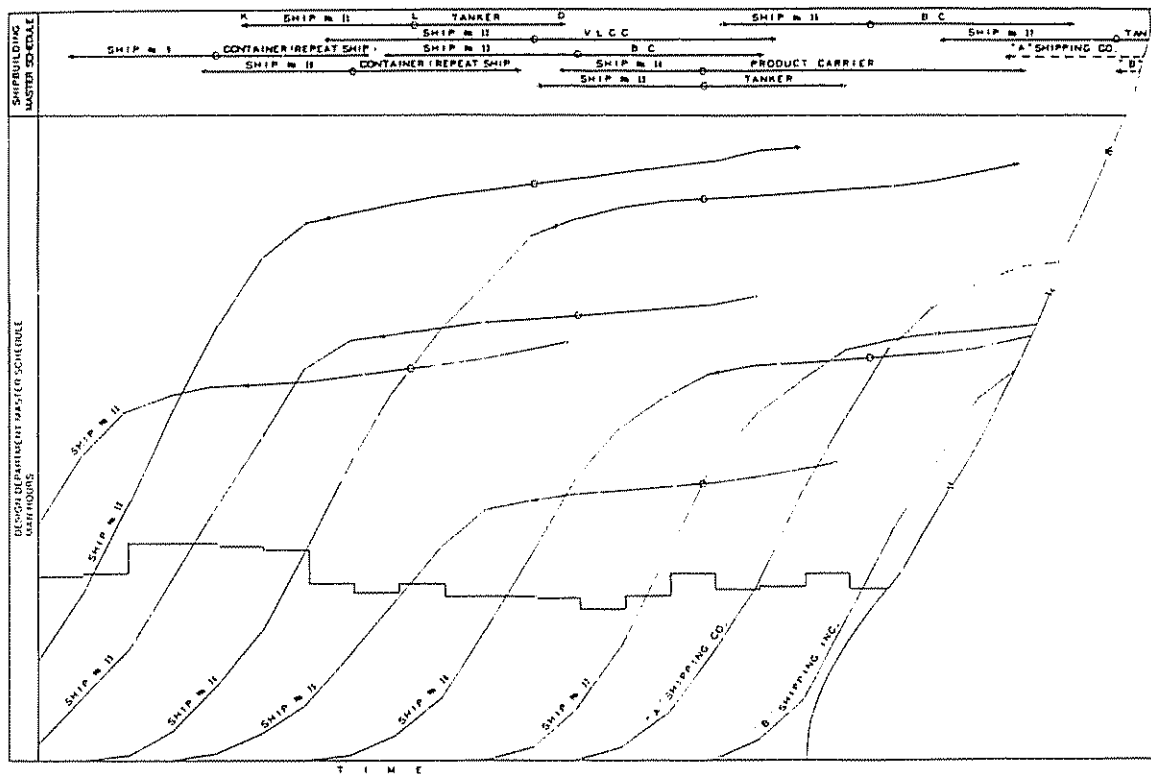


Fig 7-12. Design department master schedule

schedule, serve for planning the design work load for all ships on, or expected to be on, order. This combination of schedules composes a significant part of the design strategy to be implemented upon each contract award. Upon receiving a set of contract plans and specifications, the ship design department and each group then prepare the additional schedules shown in Figure 7-11. These schedules address the specific ship to be built.

Ship Design Master Schedule. A ship design master schedule is made by integrating the production schedules for outfitting work with the design work load imposed by the contract plans and specifications for a specific ship. As shown in typical bar chart format in Figure 7-13, a ship design master schedule indicates starting and other significant dates and assigned durations related to the preparation of such documents as:

- diagrammatics
- composite arrangements
- purchase specifications
- fitting drawings
- component manufacturing drawings
- material lists (MLS, MLF, MLP, and MLC)

Two inputs from production people are essential for preparation of the ship design master schedule. These are the outfitting milestone schedule and a hull fabrication start date.

Each ship design group schedule consists of separate parts for the key and yard plan efforts and is in accordance with the ship design master schedule. The design group schedule (see Figure 7-14) is further broken down by milestone dates and time limits for issue dates. The milestones included are start and completion dates, interface meet-

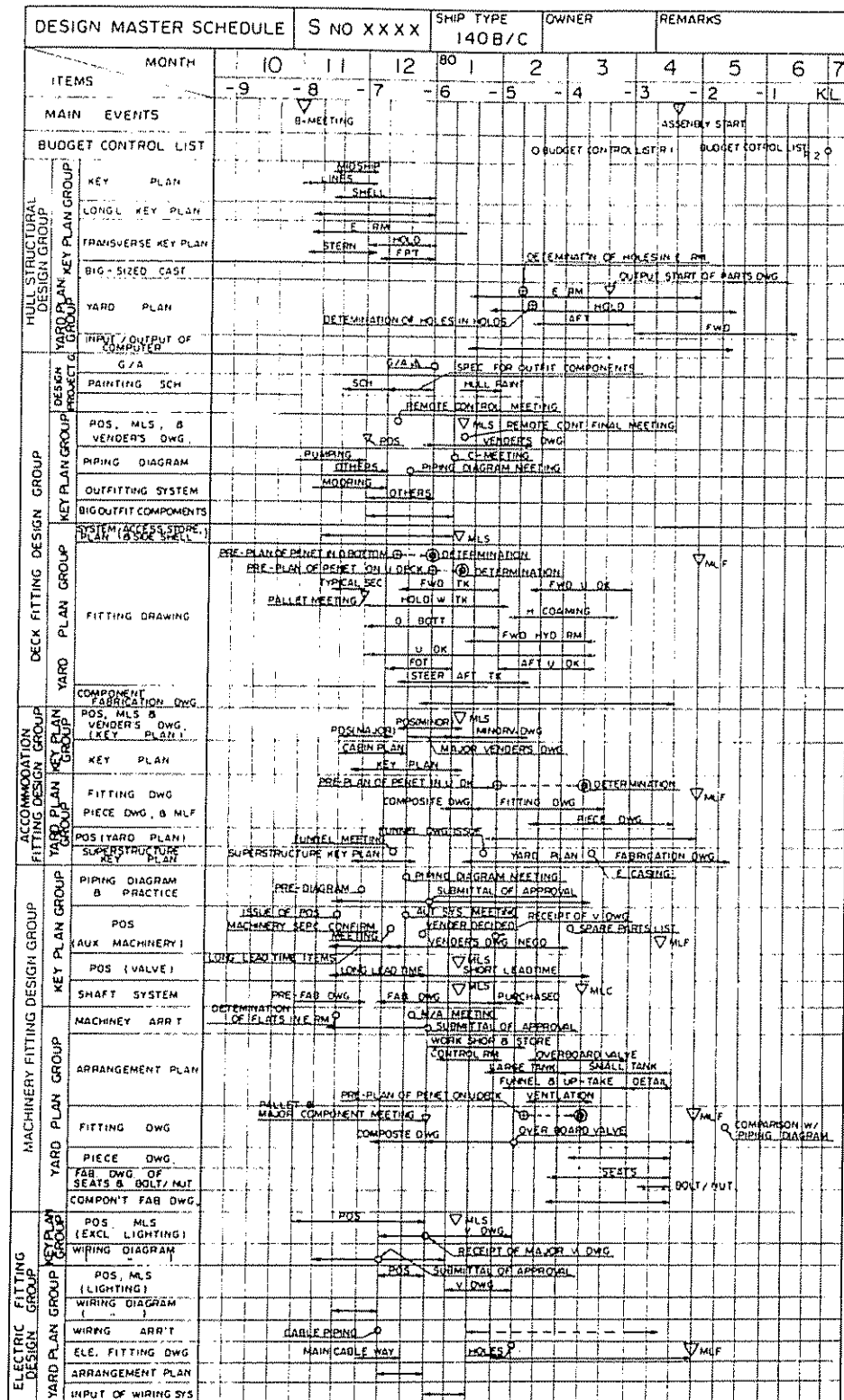


Fig 7-13 Ship design master schedule

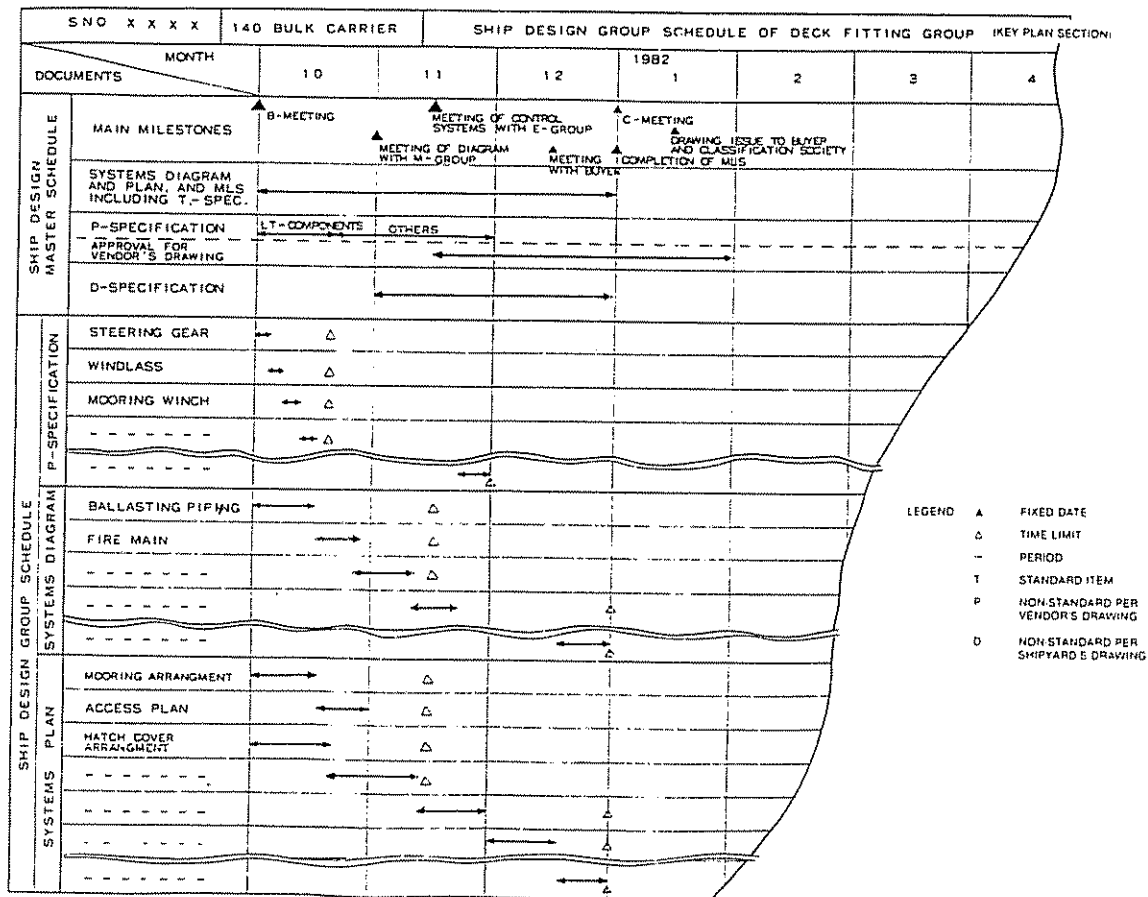


Fig. 7-14 Ship design group schedule.

ings with other design sections and groups, MLS completions, and forwarding dates for owner and regulatory body approvals.

Each ship design group schedule is based on given material lead times and production schedules. Special emphasis is applied to early scheduling of prerequisites for long-lead-time items such as:

- purchase specifications for the main engine, auxiliary machinery, and other items that can be defined from the contract specifications
- system diagrammatics and plans which specify castings, such as anchors and hawsepipes

- system diagrammatics and plans which define special fittings such as cargo oil piping diagrammatics and mooring arrangements

Drawing Issue Schedules. Each outfit specialty group makes a drawing issue schedule in separate parts for key, yard, and work instruction plans needed for a specific ship as shown in Figure 7-15. Purchase specifications and vendor drawing receipts and returns (after approval) are included. The issue schedules are used by engineers in charge to monitor and control design progress and completions by ship, and for reporting to group managers. A booklet made up of all drawing

ML (A)

S No.		TITLE	OWNER CLASS	FINAL DWG	ISSUE DATE					DRAWING ISSUE SCHEDULE MONTH												STANDARD MAN-HOUR																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																
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Fig. 7-15. Drawing issue schedule

issue schedules is sometimes used to record authorized distributions and receipts for each drawing issue, purchase specification, etc.

Design Personnel Schedules. Design personnel schedules are prepared in accordance with drawing issue schedules in order to incorporate data such as issue dates and budgeted man-hours for each drawing. Further, they identify and serve the specific people and engineers in charge having responsibilities for each drawing (see Figure 7-16).

This last of the schedule hierarchy presented in Figure 7-11 completes the description of monitoring and controlling issues at three managerial levels:

- the department manager with the design ship master schedule
- each group manager with a design ship group schedule
- each engineer in charge with a drawing issue schedule and a design personnel schedule

Besides checking progress of drawing preparation, tracking is performed for issue and

receipt of drawings processed for owner and regulatory body approvals, and receipt and return of vendor specifications processed for shipyard approval.

2.2.4 Man-hour Budget Determination System and Control. Statistical analysis of man-hour expenditures for past ship designs is the best basis for estimating design man-hour costs for a contemplated ship. However, such data cannot be usefully classified unless allowances are made for special specification requirements. Outfit specialty group man-hour expenditures for previous ships may be plotted with some allowable distribution by ship size (deadweight) and by ship type. Expenditures which differ significantly from the average curves are analyzed until the reasons for the differences are identified and classified. Each reason classification is then assigned a value in terms of man-hours or a percentage of the average man-hours by ship size and type.

When a contract is awarded, the design department manager uses these historical data for guidance in determining a proposed

SHIP NO OR PERSON NAME		MONTH												PERSON NAME	ENGINEER IN CHARGE
		I			II						III				
MAIN SCHEDULE	SHIP NO	PERSON NAME	DATE	1	2	3	4	5	6	7	8	9	10	11	12
	SHD 10	10-1							SEA 10-1						
	SHD 10	10-2										SEA 10-2			
	SHD 10	10-3													
	SHD 10	10-4													
	SHD 10	10-5													
ENGINEERING GROUP	SHD 10	10-6													
	SHD 10	10-7													
	SHD 10	10-8													
	SHD 10	10-9													
	SHD 10	10-10													
	SHD 10	10-11													
FITTING GROUP	SHD 10	10-12													
	SHD 10	10-13													
	SHD 10	10-14													
	SHD 10	10-15													
	SHD 10	10-16													
	SHD 10	10-17													
FITTING GROUP	SHD 10	10-18													
	SHD 10	10-19													
	SHD 10	10-20													
	SHD 10	10-21													
	SHD 10	10-22													
	SHD 10	10-23													

Fig 7-16. Design personnel schedule

budget for allocating man-hours to each outfit specialty group. Separately, each group manager maintains a history of standard man-hour costs in terms of pertinent indices, such as design man-hours per electric cable unit length, per piping unit length, or per unit area of decks in living areas. These indices are also used to estimate the work load imposed by a particular ship design requirement. When these estimates differ from the proposed budget allocations, the department and group managers reconcile the differences before the design man-hour budget is issued.

Once man-hour budgets are assigned, each group manager is responsible for controlling the man-hour expenditure rate, in addition to progress. Before design work starts, each group manager plans expenditures relative to time in accordance with an S-curve. If a

significant departure or trend away from the S-curve is noted during monthly entries of actual expenditures, as in Figure 7-17, the cause is identified and manpower shifts are made accordingly.

This type of tracking is not sufficient for assessment, because it yields only an indication of apparent progress. Real progress is monitored by checkoff of completions on schedules, such as for drawing and purchase specification issues and vendor drawing approvals.

2.2.5. Budget Control List. During basic design, all material needs for each ship are exactly defined or estimated by total weight by material family or cost code. This compilation for a ship is the original budget control list.

The list is employed as a budget in every sense of the word. It is used to control the subsequent design efforts and the production

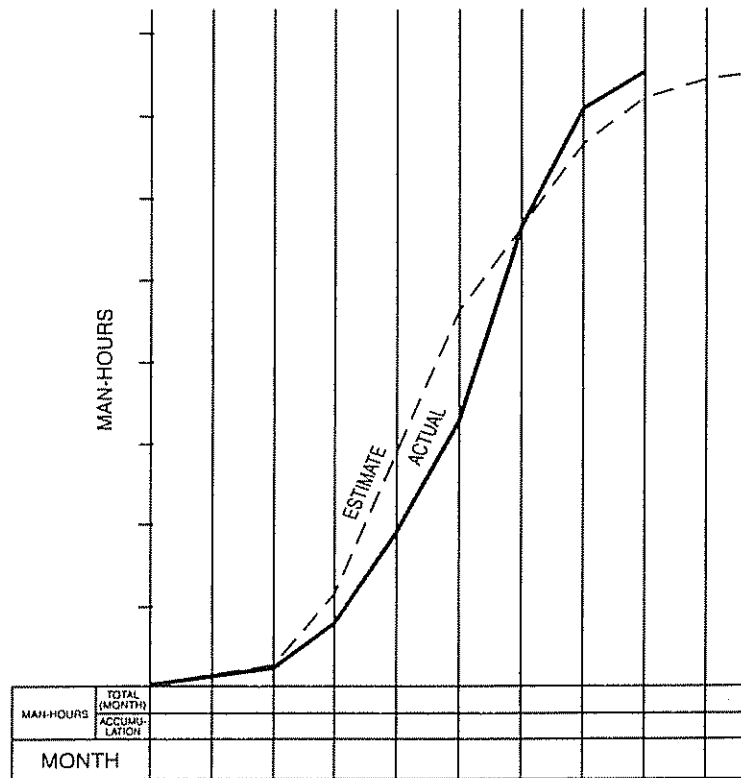


Fig 7-17 Man-hour control curve

effort so that additional material requirements cannot be added without justification and specific approval. By employing parameters derived from past normal performances which relate fitting man-hours to weights, the list becomes a working budget for both material and man-hour expenditures. Thus the budget control list is a significant mechanism for controlling the cost of an entire shipbuilding project.

During key plan preparation, the budgeted material is allocated by system, through the preparation of material lists by system (MLS), which more exactly define material needs. Items which can be counted from system plans (such as for a mooring system) and diagrammatics are indicated by weight and piece. Items which cannot be counted are listed by total estimated weight by material family or cost code. This refined knowledge is

substituted to produce the first revision to the budget control list.

When material quantities exceed the budget control list prepared during basic design, the reasons for the differences are examined. When confirmed, both increases and decreases are incorporated in a first revision to the budget control list. This list becomes the material and man-hour budget for control of the remaining shipbuilding effort, as well as feedback which basic designers employ to improve their material definition techniques. The first revision to the budget control list is just as important as key plans for specifying and controlling the work instruction plan effort.

Material lists are prepared to match fitting work instructions (MLF) and manufacturing work instructions (MLP and MLC) during the preparation of work instruction plans. Detailed quantities are indicated by

piece and/or weight by material item for all materials. Special effort is made to stay within the material quantity limits imposed by the first revision to the budget control list. Again, reasons for differences are examined, and, when confirmed, both increases and decreases are incorporated in a second revision to the budget control list. Thus, each revision, along with progress of design development, facilitates monitoring both material and man-hour costs for a current shipbuilding project, and provides feedback to guide those responsible for work in earlier stages on the next shipbuilding project. Upon completion of the shipbuilding effort, the second revision is replaced by a list of actual costs, which is more accurate feedback.

2.2.6. Basic Scheduling. While planning is primarily involved with the definition of required tasks and resources, scheduling provides for the commitment of allocated resources to specific times. Basic planning and scheduling are inseparable for overall shipyard planning. Planning, insofar as it includes the allocation of resources and the sequencing of work packages, is meaningful only in the context of a specific time period for which top management, in consideration of the shipyard's entire work load, authorizes sufficient resources. Thus shipyard long-range planners are inescapably involved in scheduling. Their mixed output, which is the framework for more detailed planning and scheduling, consists of:

- ship construction principal events schedule
- allocations by weight, cutting length, welding length, painting area, electric cable length, etc.
- man-hour allocations
- work load scheduling
- productivity measurement

At the next level, planners who are concerned with production methods, allocating

resources, and sequencing are organized in groups which match the outfit specialty organization. They, too, and for the same reasons as for long-range planners, are inescapably involved in scheduling. Their output is a refinement of the applicable framework prepared by long-range planners. Schedules produced at this level include:

- budget decisions
- milestone schedules
- outfit group master schedules
- monthly schedules
- weekly schedules
- pallet requirement schedules for material
- work instruction drawings (MLF) issue schedules

Production schedules form the framework which assists the flow of information between the various shipyard functions. This information flow is necessary to ensure completion of a ship in an efficient and timely manner. Schedules are control mechanisms and are the means by which planned work packages are conveyed to the work force. Schedules vary in detail according to the function they are intended to perform and are usually organized in hierarchical fashion.

Scheduling is simplified by the organization of information to support zone outfitting. Figure 7-18 illustrates how scheduling can be organized in a hierarchy. A principal events schedule can serve as the basic schedule for operations by fixing about 30 events, such as dates for main engine landing, stern tube boring, boiler light-off, and generator tests. This schedule is supported by the block assembly schedule and erection schedule. The block assembly schedule specifies when and where blocks will be assembled and serves as the basis for determining when on-block outfitting will be performed. The erection schedule specifies when blocks and units will be joined together at the erection site and is the basis for outfitting milestone schedules

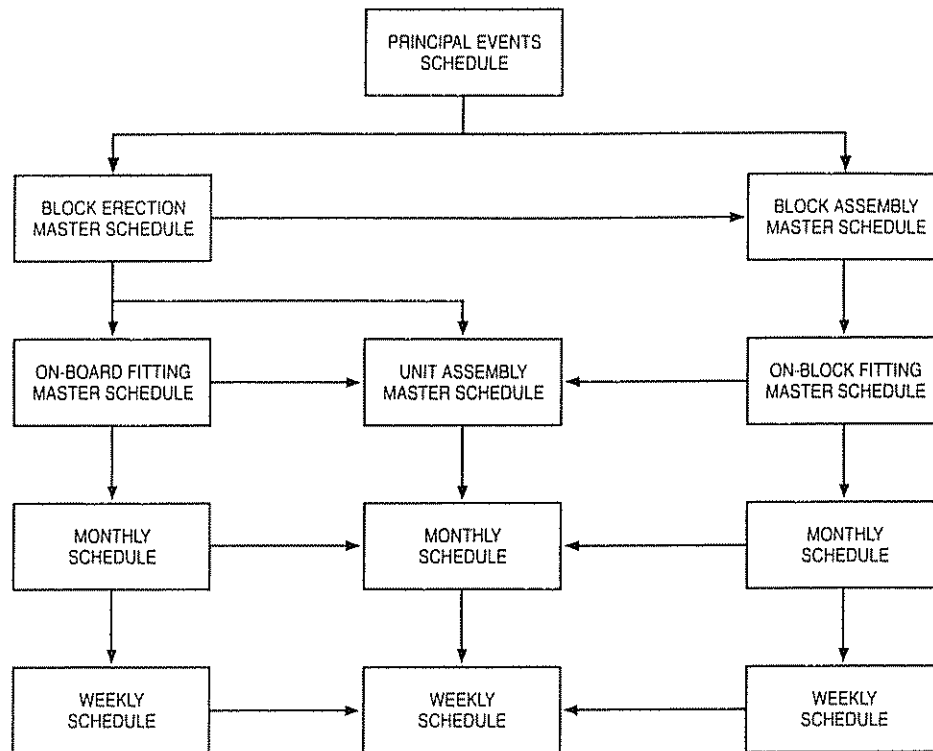


Fig 7-18 Scheduling hierarchy

These schedules serve as the bases for more detailed schedules.

Each milestone schedule is further subdivided to provide implementation orders to a particular group. However, since they are all derived from the same milestone schedule, there is coordinated implementation for

the hull, machinery, and superstructure sections and fabrication shops. This process is illustrated in Figures 7-19 and 7-20. In turn, these schedules are used to support even more detailed schedules, such as monthly and weekly schedules, as illustrated in Figures 7-21 and 7-22.

3. Planning and Scheduling

The specifics of the planning and scheduling functions are addressed in this section. The planning and scheduling process is presented in stages directly related to the design cycle (see Figures 7-23 and 6-1). These stages include basic planning, major detail planning, working detail planning, and work instruction planning. Basic planning parallels basic design. Major detail planning and part of working detail planning correspond to functional design. The transition from system to

zone orientation, which occurs in transition design, begins after working detail planning has begun. The end of transition design and working detail planning correspond. The final stages of design and planning and work instruction design and planning occur simultaneously. These stages of planning will be discussed in detail in Sections 3.2, 3.3, and 3.4.

Hull construction, even for outfit-intensive ships, including naval vessels, imposes the primary physical restrictions on the ship-

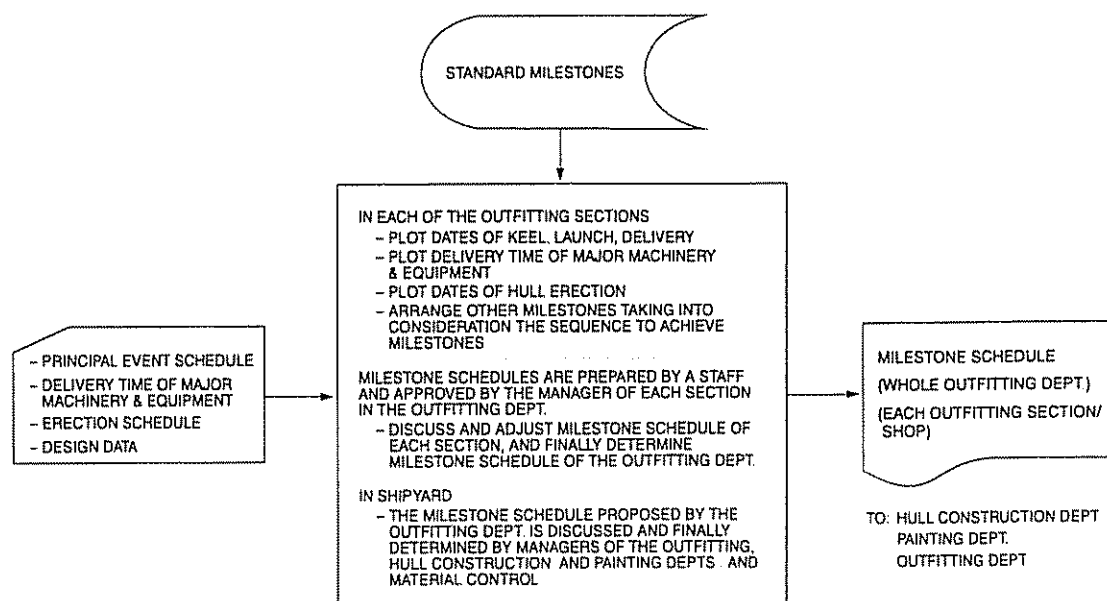


Fig. 7-19 Milestone schedule

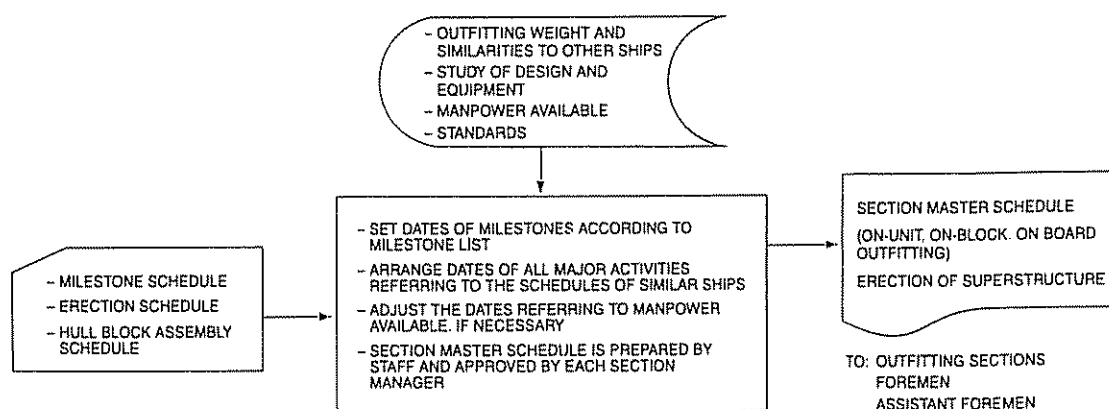


Fig. 7-20 Outfitting master schedule

building process. Consequently, hull construction planning and scheduling take the lead responsibility. Hull construction planning and scheduling will be discussed first, followed by the overall planning and scheduling cycle. Although hull construction planning and scheduling take the lead, considerations of outfitting and painting are continually addressed throughout the entire process. In fact, structured incorporation of these con-

siderations in the planning and scheduling process is critical to productive group technology shipbuilding. This integration of hull construction, outfitting, and painting is evident in all aspects of the process, including planning and scheduling.

3.1. Hull Construction Planning

In addition to the need to accommodate outfitting and painting, several other factors in-

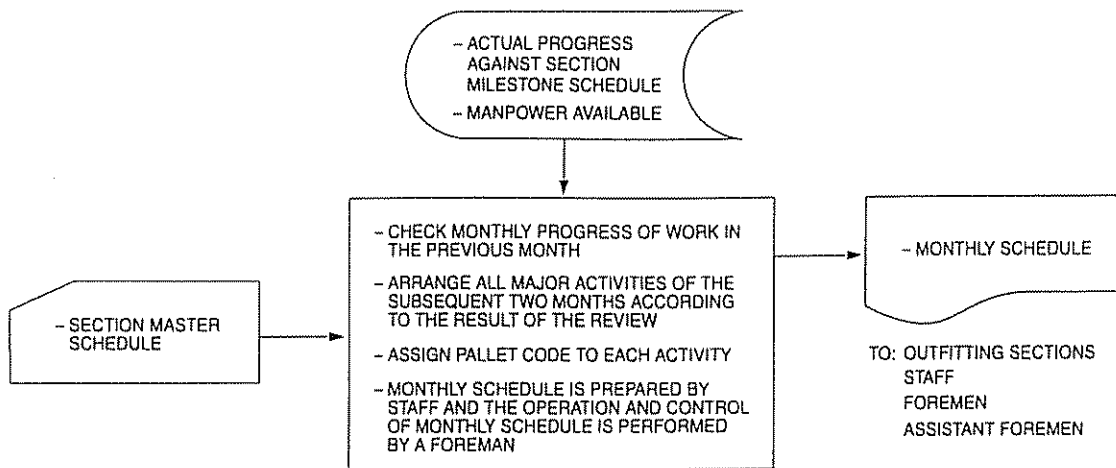


Fig. 7-21 Monthly schedule

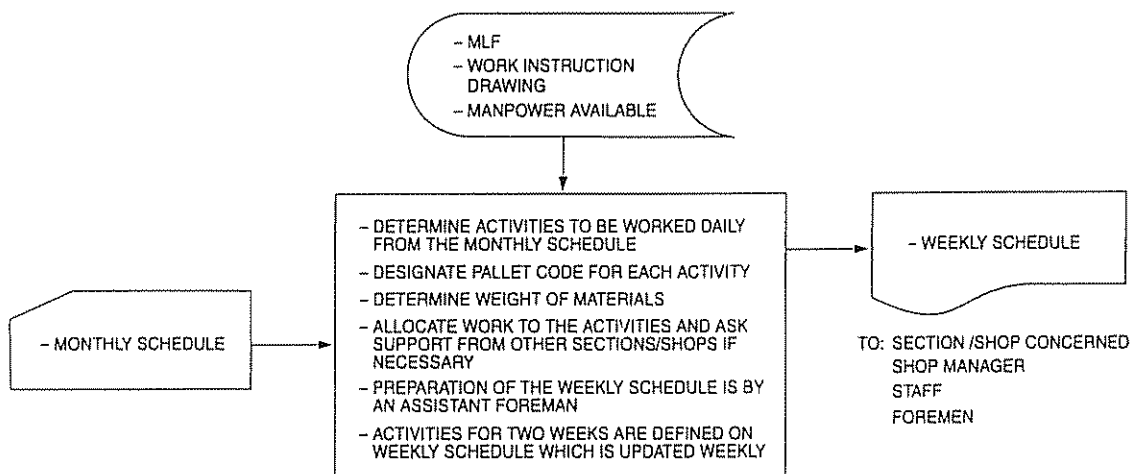


Fig. 7-22 Weekly schedule

fluence the planning of hull construction methods. They include timely completion of key and yard plans, which implies timely transition from system to zone (interim product) orientation. The speed with which these processes are executed depends, along with other factors, on:

- the degree to which the hull construction planning group is organized to communicate "how to build" to the design people responsible for describing "what to build" in key and yard plans

- how far the key plan subgroup extends preparation of key plans beyond owner and classification society approval requirements, such as with more-detailed sections and profiles
- how well designers are organized and disciplined to minimize the effect of design changes through standardization of design methods and schedule adherence
- the effectiveness of the file of standard material items (including vendor catalog items declared as shipyard

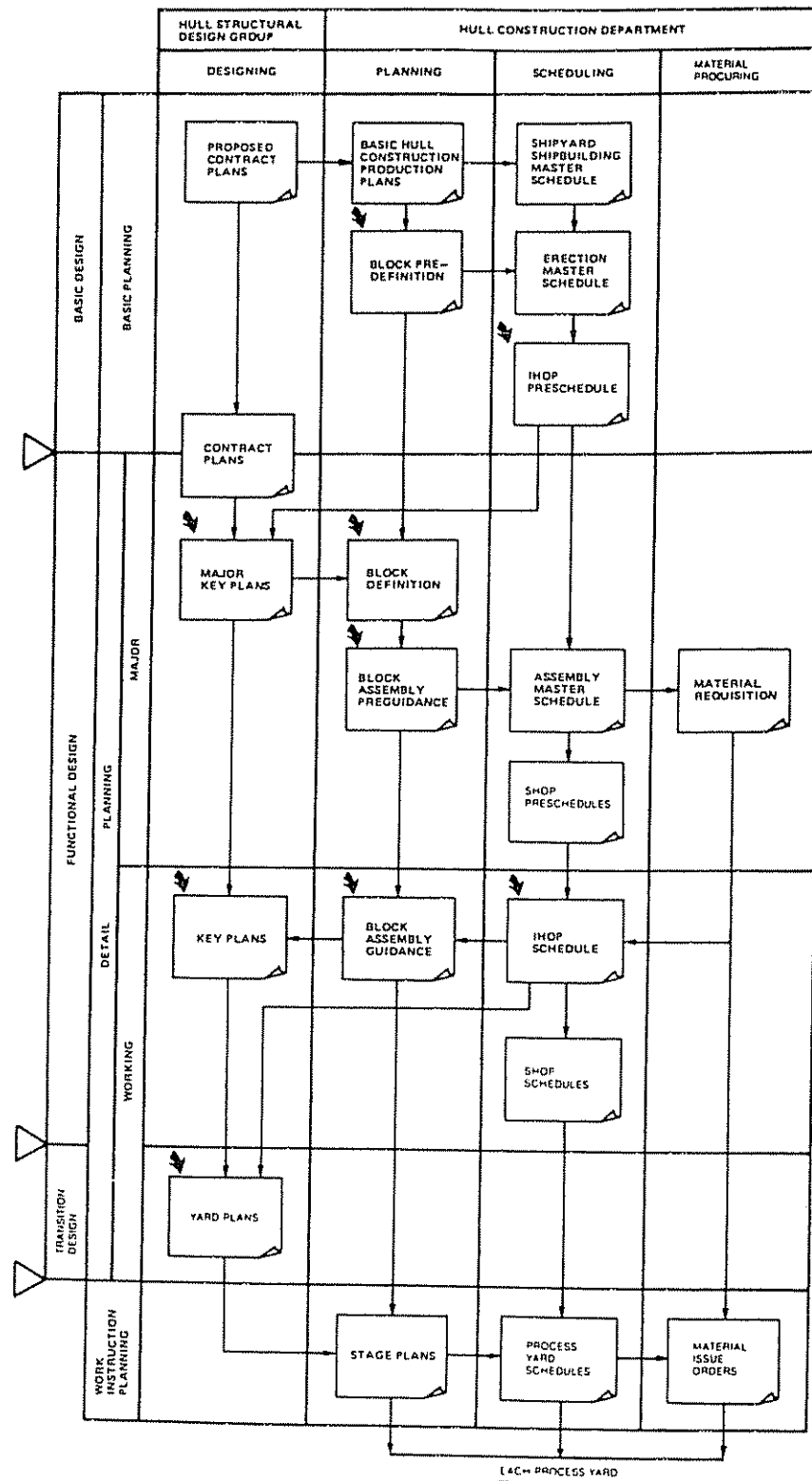


Fig 7-23. Planning and scheduling cycle

- standards for which design data are already available)
- the degree of standardization of hull construction planning items (procedures, scheduling, feedback, basic data)
- the degree of standardization of work processes (process lanes, jigs, and data collection and classification)
- adequacy of work instruction plans (for example, if all work instructions were described only in plans, assembling a small sub-block would require a complex drawing beyond the comprehension of all but a few skilled people)
- the effectiveness of accuracy control measures (see Chapter VIII)
- organization of hull construction schedules
- organization of process lanes

The organization of hull construction schedules and process lanes are important factors and are discussed in more detail below

3.1.1. Hull Construction Schedules. The integrated hull construction, outfitting, and painting preschedule is an erection master schedule upon which outfitting and painting controls are interposed. This integrated preschedule is the master schedule which governs its own subsequent refinement and the development of detail schedules for outfitting and painting, as well as hull construction. Because of this interlinking, changes in the master schedule can have an adverse effect on detail schedules. Thus, creation of schedules requires particular attention to organizing integrated work processes and forecasting workloads by stages. Each proposed hull construction work package classified by ship zone /problem area/stage should be carefully checked for duration and its status in a sequence of such work by people responsible for design, outfitting, and painting. Properly organized, integrated work processes ensure

that the structure of work packages is consistent for hull construction, outfitting, and painting. Forecasting work loads by stages ensures that the volumes of block assembly work classified by problem area/stage are determined and leveled. Also, for each work package classified by problem area/stage, checks are made to confirm sufficiently available facilities and space and to determine the effect of previously scheduled work. In addition, a schedule tracking system is necessary to create feedback needed to keep work flows leveled and to guide future production engineering developments.

3.1.2. Process Lanes Effective process lanes must be organized independent of how a contemplated hull is to be subdivided for designation of blocks, subassemblies, outfit units, and parts. System and zone are characterizations of a ship design. Problem area and stage are categories of the work process. As much as possible, zones are contrived so that they require the right kinds and amounts of work to match preferred problem area classifications.

Effective, integrated process flows require both flexibility and the balancing of considerations of the facility, production organization, design, planning, and material control. The complete portion of a process flow within a manufacturing level is dedicated to manufacturing one family of interim products and is subdivided into stages, each of which is specialized for the performance of one or more tasks. For example, stages in a process flow for assembling a large quantity of similarly sized sub-blocks are laying out, fitting, welding, and distortion removal. The stages, including outfitting and painting stages, are arranged in accordance with a sequence by process flow and to feed interim products where they are needed next in another process flow. For example, egg-box framing for a flat panel block is completed near the site where flat panel blocks are assembled.

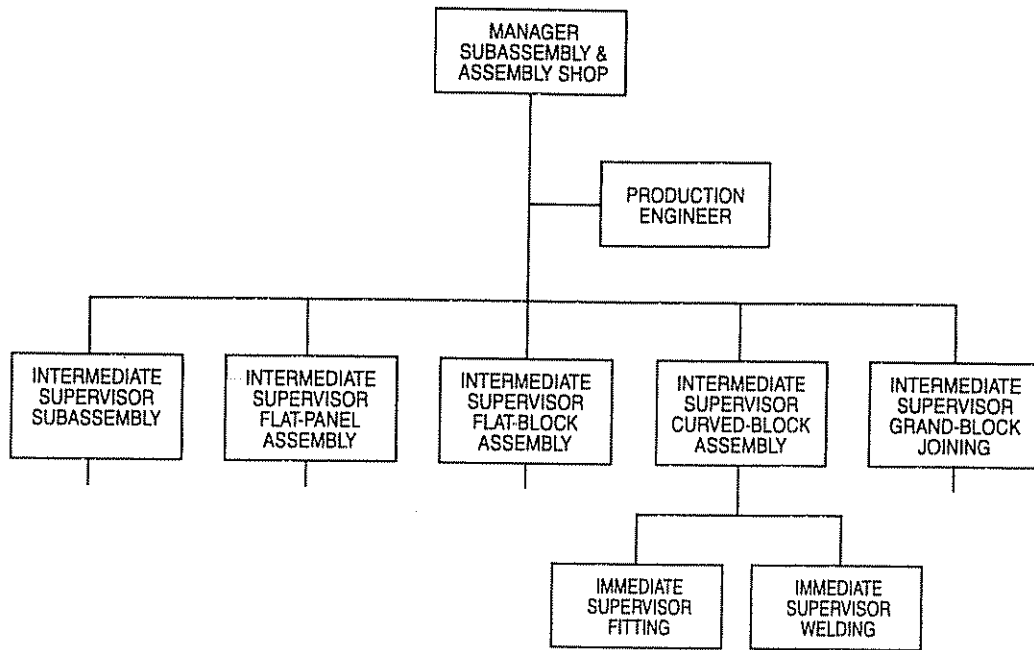


Fig 7-24. Shop organization by zone/problem area/stage

Process lanes, for administrative purposes, consist of a number of contiguous stages that may be aligned within one process flow or across process flows. An example of the former is a conveyor-equipped production line for assembly of similarly sized sub-blocks; an example of the latter is a cell which includes marking and cutting for parts for more than one family, typically parts for curved and flat panels and internal and built-up parts. Process lane perimeters sometimes change, dependent upon rates of work flows and supervisors' control spans. Therefore, shop supervisors are organized to match the organization of process lanes (see Figure 7-24). Yard plans are also organized by process lane, and a systemized hull parts code employing symbolic logic is used to identify interim products by family and their required flow paths through various manufacturing levels.

3 1.3. Communications. Good communications are necessary between the hull structural design group and the hull construction department. Equally important are good commun-

ications between each of them and their counterparts for outfitting and painting. Communication and feedback channels are shown in Figure 7-25. These are typically concerned with coordination and integration of design and production schedules, block definition, assembly and erection plans, organization of information, and requirements for block dimensional accuracy.

Hull structural design schedules are coordinated with other design schedules through specific meetings and other communication exchanges. This facilitates input from the various outfit design groups. The determination and scheduling of these events are based upon mutual agreement, as they become milestones upon which all parties depend. Standard milestones which have been used for previous ships are preferred. Block assembly and erection schedules are integrated with outfitting and painting schedules. Outfitting and painting procedures must be written before preparation of block assembly and erection schedules in order to facilitate their integration. Further, a schedule tracking system

is needed so that hull construction, outfitting, and painting field engineers can monitor progress of work packages.

Block definition is established in coordination with outfitting and painting requirements in order to minimize on-board work. For outfitting and painting that cannot be done on-unit, discussion centers on modifications to block boundaries that facilitate outfitting and painting on-block and on-board. On-block work is favored, to minimize on-board work. The block assembly processes are explained to outfitting production groups to facilitate their advance planning for effective on-block and on-board outfitting and their engineering of required outfitting processes. Their results are fed back to the hull construction planning group. The need to understand each other's responsibilities makes it important that the block assembly process and process lanes for block assembly be the subjects of written descriptions.

Separate process lanes are needed for each block category. The most obvious such classification is the flat panel block, for which real work flow is effective. Another is curved

panel block, for which all required stages for each such block are scheduled for one pin jig site. Other process flows separately address fore, aft, and engine room inner bottom blocks, because their assembly imposes different problems and these are distinct problem areas.

Contiguous stages of the process lanes are grouped into cells for administrative purposes. Space for on-block outfitting and painting stages is often provided adjacent to the site for the last stage of block assembly. However, flat panel blocks for an inner bottom often justify an on-block outfitting stage interposed between block assembly stages. For example, following completion of a tank top panel, the stages are: fitting egg-box framing to tank top, welding, on-block outfitting of inner bottom pipe, fitting bottom panel, turnover, and welding egg-box framing to bottom panel. Regardless of their locations, on-block outfitting and painting stages are controlled respectively by outfitting and painting supervisors.

The comprehensive planning and scheduling needed for effective hull construction, as shown in Figure 7-23, creates an excellent

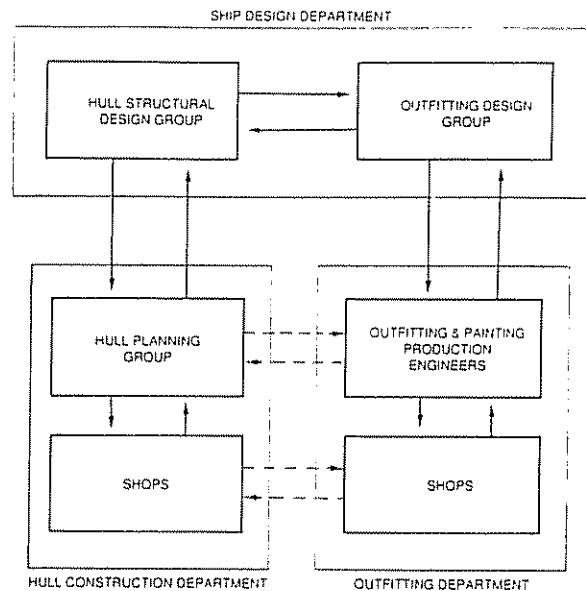


Fig 7-25 Communication and feedback channels

framework on which to impose similar needs for effective on-block and on-board outfitting. Thus, it is natural for the hull construction planning group to have the lead responsibility for the organization of an integrated information system. Such efforts are also most effective when performed systematically in accordance with standard events. In addition, such efforts are facilitated by coordination of timing for all phases of design development between the hull structural and various outfitting design groups, and standardization of outfitting impositions on structure, such as penetrations and reinforcements.

Discussions that evaluate the required dimensional accuracy of blocks to facilitate outfitting concentrate on minimizing on-board outfitting work. Inaccurate blocks require more work and greater access to butts and seams during the erection stage. Special access is needed for scribing and trimming margins and installation of numerous fitting devices. Further, a block panel that is not flat enough requires margins in auxiliary machinery foundations and in supports for outfit units to be landed. The required marking and trimming during outfitting on-block is rework. Blocks which are inaccurate also cause some pipe pieces which could have been fitted on-block to be deferred for less efficient fitting on-board. Thus, the number of fittings and the efficiency of outfitting on-block are both affected by the dimensional accuracy achieved by the hull construction processes. An accuracy control system is necessary to address these requirements (see Chapter VIII).

3 1 4 Production Planning Standards and Modules. The goals of standardized and modularized planning for hull construction are to increase the speed, accuracy, and consistency of production data communications, improve productivity of production planning, and contrive interim products which better match production facilities and work processes. Co-

operation between design and field engineers is required to achieve these goals.

Standards and modules of production planning may be grouped into two categories, according to the impact of the plan and the degree of managerial control exercised. Those plans which affect a firm's shipbuilding system and which are common for building all ships regardless of design differences are categorized as long-term (controlled). Short-term plans are not controlled and may be adopted and changed at the discretion of the hull construction department to suit particular ships to be built. Safety at work sites is addressed in both categories.

The following are examples of effective production planning standards for shipbuilding:

- designer's guidelines for production processes
 - block divisions
 - capacities of production processes
 - parts fabrication and assembly processes
- design standards
 - structural design by zone by ship type
 - structural calculations
 - structural reinforcement
 - vibration prevention design
 - design details, such as for part ends, scarfs, and slots
 - configurations of bilge keel, round gunnel, etc.
- code for manual and computer-aided preparation of design details and work instructions
 - slots
 - scallop, drain holes, air holes, manholes, and lightening holes
- symbolic parts code for workers to readily determine required parts fabrication and assembly work stage routing
 - parts identification

- designation of required interim product manufacturing levels
- work instruction symbols standard for designers prepared by process engineers in the hull construction department
 - block names
 - edge preparations
 - amounts of excess
 - welding processes, etc
- work instruction symbols standard for shops prepared by process engineers in the hull construction department
 - work instruction plans
 - welding control parameters
 - mold loft data
- parts fabrication and assembly process standards
 - edge preparation for each welding process
 - conduct of each welding process
 - conduct of each parts fabrication and assembly process
 - correction of parts fabrication and assembly errors

The following are examples of controlled standards for planning and engineering hull construction:

- design standards
 - shell plate widths and thicknesses to minimize the number of seams
 - type of shape for longitudinals, e.g., built-up tees or unequal leg angles
 - open or tight fit type cutouts for passage of longitudinals
- accuracy performance standards
 - welding and distortion removal shrinkage factors for parts fabrication and assembly processes
 - locations of finish cuts and margins for erection seams and butts
 - criteria for cutting and assembly workmanship

- standard ranges and tolerance limits (see Chapter VIII)
- process standards
 - work procedures for each workstation
 - checklists for each workstation
- safety standards
 - safety regulations for each workstation
 - safety checklist for each workstation

3.2. Basic Planning and Scheduling

During negotiations with a prospective customer, the developing basic design is reviewed by hull construction department production engineers. Incorporating feedback from production engineers in contract plans before award avoids disruptive changes and associated negotiation and schedule adjustment problems after contract award.

During the period when the basic design for a ship is being investigated, the developing midship section and general arrangement should be critiqued by the hull construction planning group. Such review, always with regard for the need to facilitate outfitting and painting, addresses the following items:

- hull structure producible with minimum man-hour cost
 - longitudinal frame spacing and shell plate thickness
 - transverse frame spacing and shell plate thickness
 - range of high-tensile steel plates
 - type of longitudinals (built-up tee, angle, etc.)
- minimal scrap ratio
 - summary of the variety of plate thicknesses
- block definition
- plate straking
- block assembly processes

This timely interchange of ideas is mutually beneficial, as the alternative is to risk more

changes, which are disruptive in drawing offices as well as in shops. As a consequence of such input to the basic design group, a build strategy featuring productive ideas based on the principles of group technology becomes part of the initial contract.

3.2.1. Basic Planning. When possible, the hull construction planning group performs basic planning before contract award. This pre-award planning provides feedback to basic designers and a build strategy which is reflected in block predefinition and the integrated preschedule. These efforts enable rapid startup on contract award.

A formal release of contract drawings, which marks the end of basic design, enables the hull construction planning group to finalize basic planning. Specific plans and schedules that are finalized at this time include steel material procurement plans and the schedule for issuing key and yard plans. Thereafter, the basic planning guides production tactics, the flow of information from design, the schedule for integrated design development, and the preparation of work instructions. During these activities, the hull construction planning group assumes leadership.

3.2.2. Basic Hull Construction Production Plans and Schedules. Based on the formally released contract plans, the hull construction planning group prepares basic hull construction plans and schedules, including:

- hull erection layout plan
- block predefinition plan
- hull construction processes plan
- hull erection master schedule
- budget control work volume
- shipbuilding activity timing schedule

The hull erection layout plan is prepared in bar chart form. It is based on the shipbuilding master schedule, which provides dates for start fabrication, keel laying, shifting,

launching, and delivery for each ship under construction. The chart enables the hull construction planning group to check for adequate shipyard space, such as for the storage of completed blocks and for the assembly of grand blocks, to fix the positions of temporary cranes for on-unit, on-block, and on-board outfitting, and to anticipate other problems caused by building ships simultaneously.

Block predefinition is performed by production engineers using a midship section, a general arrangement, and sometimes a machinery arrangement. The objective is to achieve high productivity in the integration of hull construction, outfitting, and painting. Major considerations are special hull structure and other features, special owner requirements, and master plans for outfitting and painting processes, such as for holds, engine rooms, etc. The block predefinition plan is produced in two parts, a midship section block predefinition plan and a general arrangement block predefinition plan.

A production engineer uses the block predefinition plan to develop a hull construction processes plan. This plan must be developed to the satisfaction of the hull construction department, shop, and section managers and the senior production engineer. It includes the following sections:

- block definition on a midship section
- size, weight, and quantity of blocks by each category (bottom, side, longitudinal bulkhead, upper deck, etc.)
- joining blocks to create grand blocks
- erection sequence, including sequences by block categories
- specific application of nesting, marking, and cutting methods, and a scrap ratio target
- block assembly processes and different aspects of the processes for each category of blocks represented in a midship section which shows main and internal structure

- specific application of scaffolding methods and special work units for erection
- specific application of automatic welding processes for erection

The hull erection master schedule network is the responsibility of a production engineer assigned to the erection shop. It must coordinate with counterparts in the outfitting shops, the on-board outfitting schedules. The block predefinition plan provides the principal guidance for this schedule. Particular attention is given to large machinery items, such as diesel generators, which are separately landed before additional blocks enclose the machinery space. This process requires each such outfit item to be scheduled for erection just as if it were a block.

The budget control work volume is prepared using the midship section and the block predefinition plan. A hull construction production engineer allocates man-hours by using parameters based on normal past performances that relate man-hours to factors such as:

- hull weight by mild and high-tensile steel, block weight, and sub-block weight
- welding length for subassembly and block assembly
- parametric welding length for erection (by each weld size and position)
- quantities of blocks by hull region (hold and engine room)
- quantities of scaffold planks by hull region (aft body, fore body, and engine room)

The shipbuilding activity timing schedule is developed using the block predefinition plan, the erection master schedule, the basic outfitting and painting plans, and the outfitting master schedule prepared by production engineers in the outfitting department. This schedule is produced in bar chart form by a

hull department production engineer. It shows the timing required for each process, including outfitting and painting processes from yard plan issue to erection for each block. Further, the shipbuilding activity timing schedule is sectionalized to separately address each hull region. Dates are incorporated for:

- erection
- start and completion for block assembly
- issue of hull construction and outfitting drawings
- requisitioning of steel material
- issue of drawings required for material requisitioning
- erection of major outfit components (landing large items on-board during blue sky outfitting)

The shipbuilding activity timing schedule becomes a master from which all subsequent schedules are derived. It is a control mechanism for rapid startup and continuing coordination of the build strategy for which there is general agreement. This schedule is approved by the general manager only after assuring that department and shop managers are in agreement.

3.2.3 Conduct of Block Predefinition. As indicated by the following, block predefinition involves many considerations. These may be grouped by midship section and general arrangement

Midship Section

- proposed block divisions are marked, based on:
 - locations of high-tensile steel parts
 - ease and safety of required erection work
 - minimizing alignment problems for shipwrights when erecting blocks
 - limitations for employing work units during the erection process (see Figure 7-26)

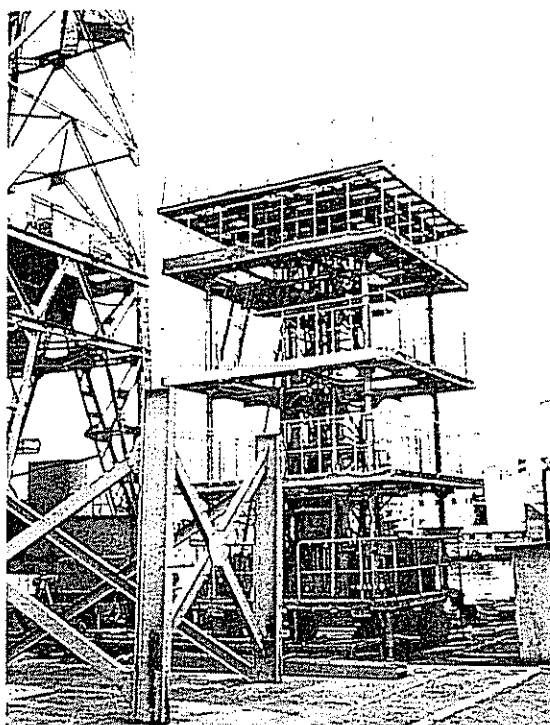


Fig. 7-26 Typical work unit

- ease and safety of block assembly work
- accuracy required during block assembly
- size and weight limitations of assembly facilities
- consistency of deck, bulkhead, and shell plate thicknesses within sub-blocks and blocks
- straking is established considering the maximum utilization of standard width plates
- block lengths are determined as a function of frame spacing (f) and whole number of frames (n) in accordance with:
 - maximum length ($f \times n$) < limiting length imposed by block assembly facilities, or considering a cargo compartment
 - maximum length (length of cargo compartment/ n) < limiting length imposed by block assembly facilities
- (whichever method yields the most similarity in blocks is the one employed)
- block weights are calculated, including fittings which are to be fitted on-block, scaffolding, and lifting gear
- required parts to be fabricated are checked to ensure that plate weights and dimensions are not excessive, and curvatures specified are within the capabilities of bending facilities
- the adequacies of subassembly facilities are checked concerning subassembly weights and heights, and the need to attach parts (minor assemblies such as brackets)
- limits of block assembly facilities are checked concerning overhead clearances, weights of egg-box framing, etc.
- after the foregoing checks are made, feedback is provided to the hull structural design group concerning:
 - facility limitations
 - types of longitudinals and types of cutouts required for passage of longitudinals
 - need for an improved scrap ratio by addressing thicknesses for transverse webs, face and web plates of built-up longitudinals, etc.
 - subassembly joints that are difficult to align
 - details regarding flat bar, brackets, etc.

General Arrangement. Block definition is separate for the parallel midbody and for the bodies fore and aft. Blocks are defined to be as large as facilities permit, always to facilitate outfitting and painting, and with specific attention given to:

- parallel midbody
 - sheer start points
 - limits of parallel midbody by tangency points to curved shell

- requesting that the yard plan subgroup maintain the same scantlings for at least four-tenths of hull length (0.4L)
- positions of bulkheads considering the cargo compartment arrangement
- positions of fore and aft engine room bulkheads and forepeak bulkhead
- deck piping arrangement
- block rigidity and stability
- fittings arranged in tanks
- setting, shifting, and removing work units
- installing and removing scaffolding
- determining the weight of each block including outfit and lifting gear
- joining blocks to create grand blocks both to shorten the erection stage and to do more of the outfitting on-block than would otherwise be done on-board
- fore and aft bodies and engine room
- limit of curvature that can be accommodated on pin jigs for assembling curved blocks
- method for landing the main engine (assembled or disassembled)
- block stability both before and after turnover
- rigidity required for block turnover and block erection with little or no reinforcement
- determining the weight of each block together with outfit and lifting gear

To increase the amount of on-block outfitting for the purpose of minimizing on-board outfitting, L-type grand blocks (see Figure 7-27), are defined. Each consists of a flat (deck) block joined to a curved (shell) block encompassing a greater volume of the region to be outfitted and painted. The yard plan subgroup is requested to ensure that shell seams do not cross decks or platforms. Consideration is given to the relationships between block butts and seams and the following:

- machinery arrangement
- tank arrangement
- control room, elevator trunk, lifting beam, workshop, etc.
- mooring arrangement
- standard ranges and tolerance limits which reflect normally achieved accuracy when bending plates for curved shell

3.2.4 *Basic Block Definition Meeting.* As production engineers in the hull construction department are working to define ideal blocks, they are providing feedback to the basic design department and to the hull structural design group. The latter investigate the proposed basic design and address items such as:

- sides for stiffeners on bulkheads
- arrangement of stiffeners considering block joints
- stiffener spacing, setting angles (as to a cambered deck) and end details
- types of cutouts for passage of longitudinals and orientations of nonsymmetrical cutouts
- provision for temporary access holes
- form of camber
- designation of shelf plates
- edge preparations
- types of slots, scallops, and stiffener ends to facilitate sandblasting

Thus, much planning of a tactical nature is discussed as a means for optimizing the strategy for the whole shipbuilding process. The basic block definition meeting is a working meeting of engineers from all departments. It is characterized by discussion of hull construction, outfitting, and painting. The meeting objectives are to coordinate the diverse recommendations, end the discussions, and produce a block predefinition plan which op-

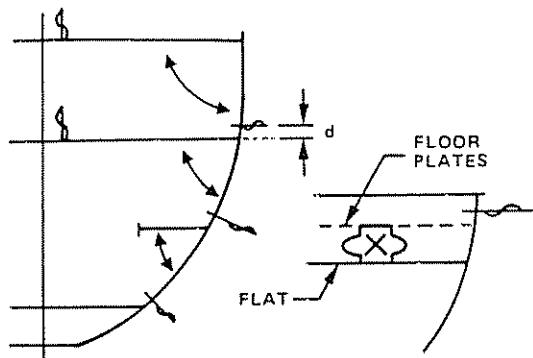


Fig. 7-27(a)

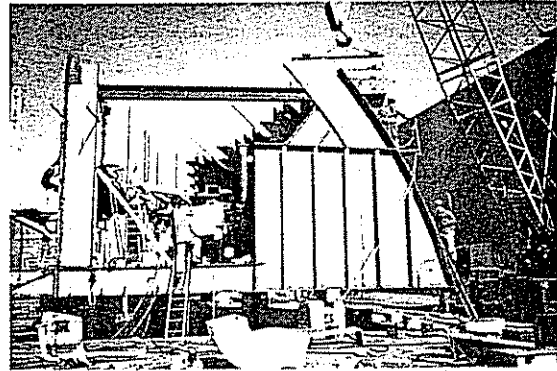


Fig. 7-27(b)

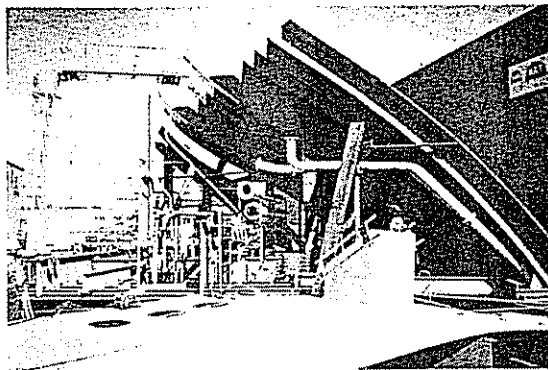


Fig. 7-27(c)

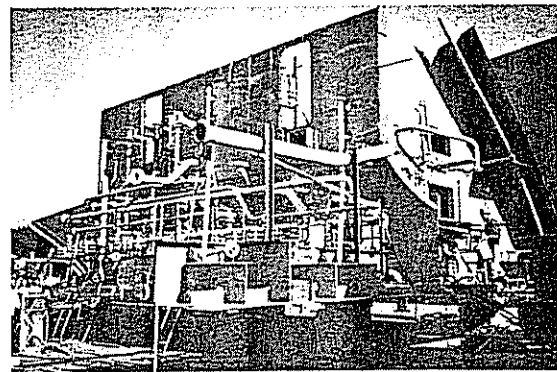


Fig. 7-27(d)

Fig. 7-27. L-type grand blocks

timizes the entire shipbuilding project. The plan reflects requirements for fast startup and enhanced productivity for which there is general agreement within the shipyard.

Figure 7-28 compares two schemes for defining blocks, one that is consistent with integration and one that isn't. Benefits are realized for hull construction in addition to outfitting and painting and include:

- more opportunities for on-block outfitting and painting, particularly outfitting and painting downhand
- fewer blocks defined
- reduced welding during erection and in difficult positions
- more stable and rigid blocks
- fewer stays and shores needed

- significantly less scaffolding required
- less damage to fittings and paint during erection

All of the foregoing significantly enhance safety.

3.3. Detail Work Instruction Planning and Scheduling

After the release of the contract plans and the completion of basic planning, the hull construction planning group initiates detail planning in two phases: major, which may be regarded as department-level planning, and working, a refinement of the former which addresses shop-level planning. The objective is to produce intermediate-level plans and schedules which facilitate the later prepa-

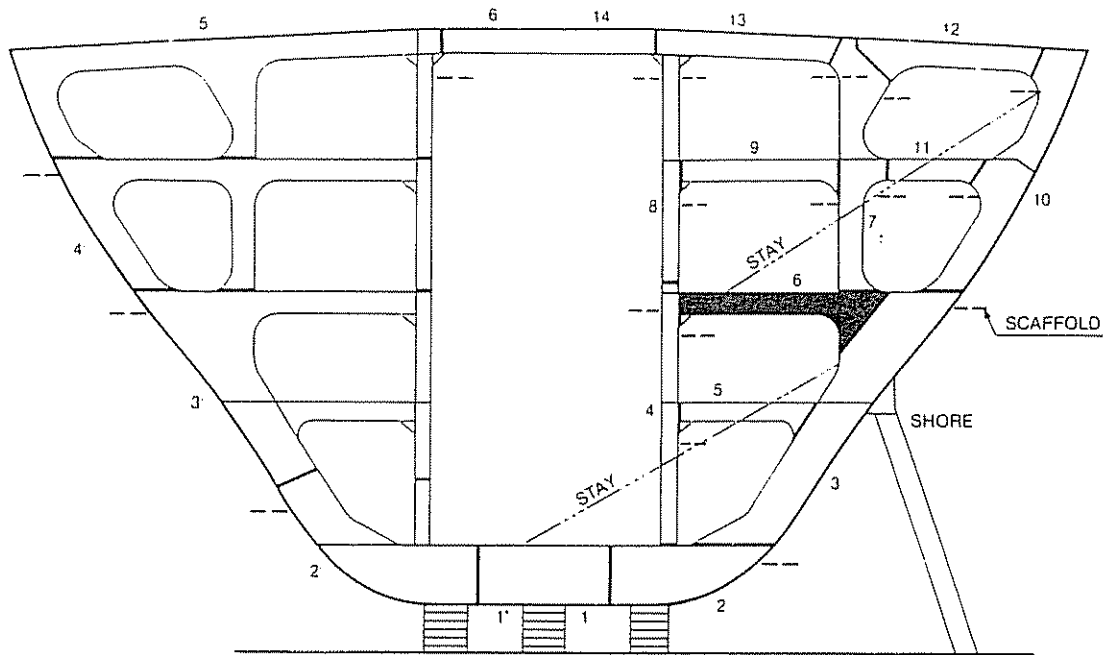


Fig 7-28. Block definition consistent with integrated HBCN, ZOFM, and ZPTM.

ration of product-oriented work instruction plans. This phased detail planning effort includes preparation of:

- detailed hull construction production plans (major and working)
- a schedule for coordinating the efforts of the hull structural design group (particularly for yard plan issue dates) and all shops of the hull construction and outfitting departments
- man-hour budgets based on parameters that are peculiar to each shop's interim product specialty

The most essential aspect of the hull planning group's efforts to facilitate integration of outfitting and painting is introduction of a product-oriented build strategy as early as possible. Thereafter, plans and schedules are refined until there is definition of a number of sequenced, short-range objectives (blocks) which are classified by problem area. Other-

wise, managers could not achieve effective operation of integrated process lanes.

Immediately after the contract drawings are released, the hull construction planning group starts detail planning of work processes commensurate with the contract plans and the block predefinition plan. The effort is divided into two phases, major and working. It is characterized by constant interchange of information with the hull structural design group to ensure that the contemplated build strategy is incorporated in key and yard plans as they are being developed, and the build strategy is adjusted, if necessary, as a consequence of owner and regulatory body approval comments on key plans.

Figure 7-29 shows the production planning flow for hull construction. The documents prepared by the hull structural design group and the outfitting department are identified. Figure 7-30 shows a production scheduling flow for hull construction which is organized to facilitate comparison with the production

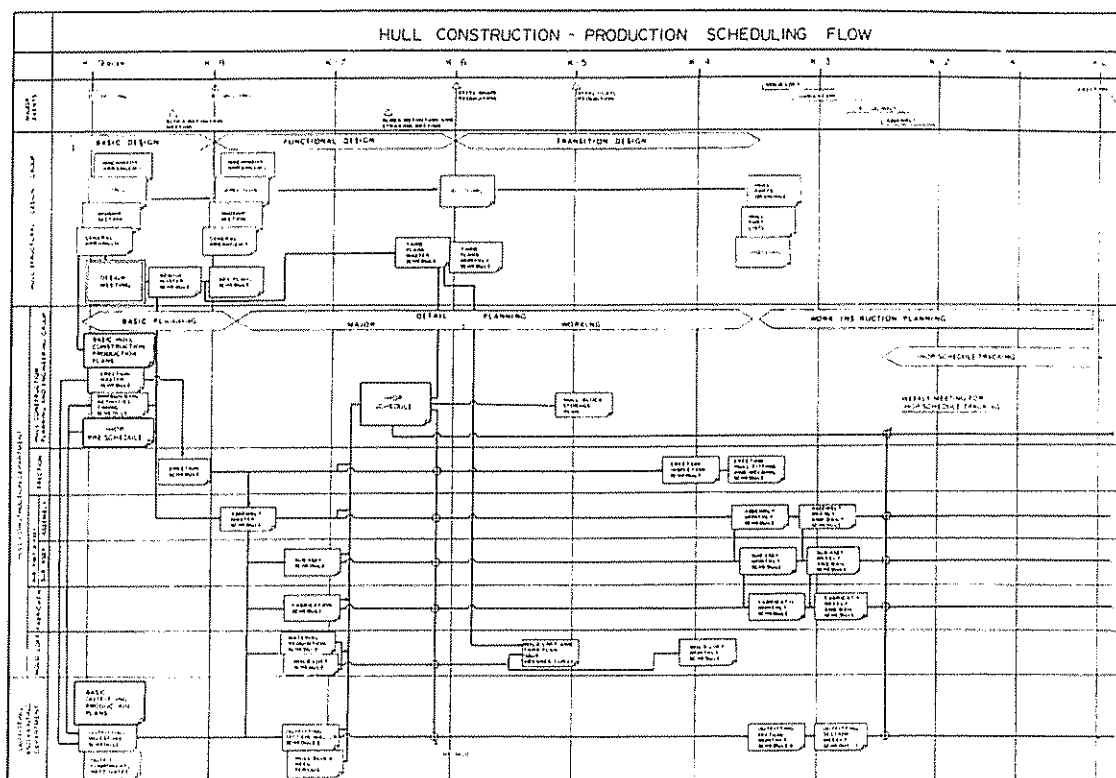


Fig 7-30. Hull construction production scheduling flow

planning flow shown in Figure 7-29. Both reflect flows through four distinct stages: basic, major detail, working detail, and work instruction. Both provide for outfitting department concerns which include painting.

3.3.1. Major Detail Planning and Scheduling

Major Detail Planning Among the items addressed in the first detail planning stage are some which influence key plans that are developed simultaneously. These are:

- detail block definition plan
- autowelding application plan
- work unit application plan
- block assembly preguidance
- midship lifting master plan
- midship scaffolding master plan

- block weight and weld length rough calculations

Block predefinition is reexamined and finalized on the detail block definition key plan. The hull body parts, especially fore and aft, which were not defined on contract plans are finalized in detail. The midship section straking is rechecked and extended into the fore and aft bodies. Seams are carefully located relative to decks and platforms to facilitate on-block outfitting and painting. The refined block definition and straking is provided as feedback to the hull structural design group.

The autowelding application plan addresses welding of erection butts and seams and is prepared in the context of the hull construction processes plan. Specific welding

methods are designated for each butt and seam and are confirmed by process engineers assigned to the erection shop. This plan is also part of the feedback furnished to the hull structural design group.

Work units may be employed to facilitate hull erection. Therefore, planning for their use and consequently the work unit application plan follow the same pattern as the autowelding application plan.

The block assembly preguidance plan covers curved portions of the hull, such as blocks that incorporate turn of the bilge and blocks of the fore and aft bodies. This preguidance is prepared simultaneously with key plans for panels and sections.

The midship lifting master plan contains guidance concerning the handling of midship blocks, large-size grand blocks, and blocks containing large quantities of outfit components. Necessarily, production engineers for outfitting and painting participate. All handling requirements are addressed (transfer, turnover, and erection alignment). Plans are prepared for shipwright and erection methods, turnovers, locations of lifting pads, and permanent and temporary reinforcements. Specific requirements for enhancing block strength, particularly for lifting and turnover, are fed back to the hull structural design group. Man-hour budgets and material costs for lifting pads, receiving guides, stays, etc., are also determined from the midship lifting master plan.

The midship scaffolding master plan addresses all scaffolding requirements except those for the engine room. The engine room design is not sufficiently developed during the major detail stage of production planning. The plan incorporates decisions regarding types of scaffolding, avoidance of interferences with outfit components, and locating scaffolding to commonly serve hull construction, outfitting, and painting.

Welding lengths for the subassembly and assembly processes are recalculated block by

block from the more descriptive design being disclosed by the developing key plans. Similarly, block weights and parametric welding lengths for the erection process are recalculated. These more accurate lengths and weights are substituted for those estimated in basic planning in order to:

- update the budget control work volume prepared during basic planning
- prepare the assembly master and other shop schedules
- update the hull steel weight in the budget control list prepared during functional design by the hull structural design group
- determine the sums of all lengths and all parametric lengths which are needed to calculate welding rod requirements

Major Scheduling. As shown in Figure 7-30, the basic input to major scheduling is an erection schedule by ship, which was prepared before contract award from an erection master schedule. The erection schedule features:

- the shortest practical erection period
- an erection sequence which is easiest for shipwrights
- durations required for aligning and fitting blocks, shifting work units, and removing scaffolding
- the date for erecting each block
- daily man-hour requirements for fitters and welders

At the start of the detail planning stage, an assembly master schedule is derived from the erection schedule, the integrated preschedule, the shipbuilding activities timing schedule, and the design master schedule. On the assembly master schedule, forecasted work is leveled, together with that for other ships using welding lengths for as-

sembly that were calculated during basic planning. This schedule displays the duration required for assembly of each block for all ships by each process flow. For example, flat- and curved-block assemblies are shown separately. It is also a master schedule for shop activities for subassembly, fabrication of parts, material requisitioning, and mold loft activities.

Next, with additional inputs from the outfitting department, specifically outfitting shop master schedules and block need periods for on-block outfitting, an integrated schedule is produced while small adjustments are made in the various shop schedules as necessary to ensure their coordination. The shop schedules, so refined, "look forward" for six months and are updated every two months, together with the assembly master schedule, by substituting more accurately determined welding lengths for those estimated during basic planning.

3 3 2 Working Detail Planning and Scheduling
Working Detail Planning. Plans which are made after key plan approvals are:

- block assembly guidance
- fillet weld on-block air test
- work access holes
- work instruction master
- finish cut and marking process
- working piece treatments
- accuracy control
- parts fabrication process lanes
- rough cutting and steel requisition
- block arrangement handbook
- mold loft and work instruction guidance
- accuracy control check

The block assembly guidance plan is a finalization of block assembly guidance, and takes into account the impact of the approval comments.

The fillet weld on-block air test plan is superimposed on a copy of a key plan prepared for approval by the owner and regula-

tory bodies. The specific test details are included for pressurizing beneath fillet welds, including positions of air fittings and air stop welds. These tests are implemented on-block so as to eliminate the need to test the same fillet welds during hydrostatic or pneumatic tests on-board.

The work access holes plan shows holes allowed for temporary access on a copy of the same key plan used to develop the fillet weld on-block air test plan. Its preparation involves coordination with engineers assigned to the outfitting and painting shops as well as the assembly and erection shops.

The work instruction master plan is the means by which common work instructions for the various work stages are provided to the hull structural design group for inclusion in the yard plans. A work instruction master plan addresses such things as:

- block code
- semiblock code
- erection sequence marks for the direction of blocks, the keel-laying block, and insert blocks
- hull parts assembly sequence for the subassembly and assembly stages
- excess allowances and edge preparations
- parts-marking techniques, such as electrophoto (EPM) or size lists
- vital dimensions needed for assembling blocks

The finish cut and marking process plan contains instructions for achieving the overall and layout dimensions for the panels on which the blocks are assembled. It specifically addresses dimensions for cutting each panel to finish size, and layout dimensions for longitudinal and transverse members.

The working piece treatments plan provides instructions regarding disposition of working pieces (padeyes, staging lugs, receiving guides, etc.) It normally is processed for

approval, as it designates which working pieces may remain as permanent fittings, which have to be removed, and what surface treatments are required after removal.

The accuracy control plan is developed as a master for accuracy control considerations that will be common to all work stages (see Chapter VIII). It provides general guidance to be included on yard plans, such as identifying the hull blocks which will be the most difficult to assemble and the types which were inaccurately assembled in the past. Specific instructions address:

- match lines needed on parts to facilitate subassembly and assembly
- reference lines needed for assembly
- specific length of butts and seams in complicated hull forms which justify margins and the extents of such margins
- checkpoints and pertinent dimensions to verify alignment of large assemblies

The parts fabrication process lanes plan indicates the types of markings to be used for internal structural parts, such as N/C, EPM, or a simple size list. It serves as input for computer-aided processing by the hull structural design group. This planning effort is performed simultaneously with preparation of rough cutting plans.

The rough cutting and steel (plate and shapes) requisition plans are needed for organizing the material requisitioning effort at an early stage commensurate with pertinent material lead times. References include key plans for types, grades, sizes, and quantities of steel and the assembly master schedule for required dates. Utilization of standard size materials and grouping of requisitions by lot by delivery date are primary considerations in preparing these plans. Planning proceeds based on some estimated quantities, because detailed plans are not yet avail-

able. Because of this need to employ estimates, the designation of standard sizes normally favors oversizing some hull construction materials. Size standards are established beforehand, and designers are urged to refrain from designating alternatives in order to minimize the percentage of scrap, maximize interchangeability of materials, and minimize storage requirements.

The requisitions of lots required by month pertain to various materials needed for a number of blocks for which there are different required dates. The requisitions are grouped into lots per month, with prime consideration given to the parts fabrication sequence. This ensures sustained work flows without the disruptive need to rearrange jigs or change machinery settings. Consideration is also given to subassembly and assembly schedules and storage areas. Requisitions for steel materials are made with reference to rough cutting plans and stocks on hand. Their issue authorizes the purchasing section to combine requirements and place orders with steel mills. Further, the planning performed is used as guidance for all marking and cutting plans which are the basis for steel material allocation sheets. These sheets are commonly used for steel material issue orders as well.

The material in the block arrangement handbook is extracted from a number of key plans. It conveys the whole ship structure and block definition. Copies are distributed mainly to managers and production engineers in the erection shop.

The mold loft and work instruction guidance plan is compiled by extracting information from many documented plans and instructions that are prepared by hull structural designers and production engineers. The information is selected and edited specifically to serve the mold loft and the stage plan section for their work instruction planning.

Formal accuracy control check and report sheets are prepared for each interim product

by block by the production engineers who have been assigned accuracy control responsibilities (see Chapter VIII). Their objective is to record variations in dimensions achieved, which, when analyzed statistically, advise how the work processes are performing. Such analysis creates the feedback needed to exactly compensate for shrinkages, such as those caused by gas cutting, welding, and distortion removal. Production engineers also use such data to control the amount of rework (gas cutting of margins and back strip welding) that will be encountered during hull erection.

Working Scheduling. Working schedules include:

- assembly, subassembly, and parts fabrication monthly schedules
- yard plan and mold loft issue curves
- block storage plan
- erection inspection schedule and erection hull fitting and welding schedule

Each monthly schedule for block assembly, subassembly, and parts fabrication orders covers the next six weeks and is updated every two weeks in order to substitute the more accurate parameters produced during transition design. The assembly monthly schedule is made in accordance with the assembly master schedule. The subassembly monthly schedule is derived from the subassembly schedule and the assembly monthly schedule. The parts fabrication monthly schedule is derived the same way. The impact of such updating requires adjustments in interim product completion dates for work load leveling, specifying the use of overtime, and/or engaging subcontractors. Shop schedules affected by the revised parameters are updated every two months.

Curves for planned issues of yard plans and mold loft data are prepared to be used as the basis for checking actual progress, includ-

ing how progress by the mold loft relates to actual yard plan issues. These visual presentations facilitate assessments of progress and, if needed, expediting measures. Updating the mold loft monthly schedule depends on yard plan issues and progress of work in the mold loft.

The block storage plan allocates space for storing completed blocks prior to their erection. This plan is prepared by a production engineer in accordance with the integrated schedule. The plan is revised every ten workdays and on each launch day. When all available space is allocated according to the block storage plan, the assembly master schedule has to be changed accordingly. Because erection work proceeds faster than assembly work, enough space is required near the erection site to ensure an uninterrupted supply of blocks for the erection shop. This means, depending on ship types, 40 to 60 percent of required blocks must be on hand before keel laying.

As controlled by the erection schedule, an erection inspection schedule is made to ensure meeting start dates scheduled for on-board painting. This schedule is updated in the same way as other monthly schedules. It indicates dates for tank testing, cleaning, removal of scaffolding, etc. Next, the erection hull fitting and welding schedule is prepared to fix a duration for fitting and welding between the date each block is scheduled for erection and its scheduled test date. The manning plan for erection fitters and welders is made simultaneously with this schedule in order to be sure that they are compatible.

3.3.3. *Work Instruction Planning and Scheduling.*

Yard plans are product oriented and conform with requirements for process lanes in accordance with hull construction production working plans prepared by the hull construction planning group. Yard plans are organized by zone, and their preparation marks

the end of transition design. Further development of needed documents is by stage and is managed by the hull construction planning group during the work instruction planning stage.

Work Instruction Planning Work instructions address the work for each stage within a process lane. They are prepared both in the mold loft and by the work instruction plan section in accordance with requirements established by the hull construction planning group. Since computer terminals are located in most mold lofts, some planning responsibilities that involve work instruction preparation have been shifted from the hull structural design group to the mold loft. These include hull parts lists by stage, marking and cutting plans for parts fabrication, bending plans, and height tables for setting pin jigs. Erection work instructions prepared in the mold loft include shipwright dimension plans and supporting block arrangement plans. The work instruction plan section is a companion organization to the mold loft and is responsible for such instructions as:

- the assembly plan for subassembly
- the assembly plan for block assembly
- the block finish cut dimension plan for block assembly
- the block lifting instruction plan and scaffolding arrangement plan for subassembly, assembly, and erection (padeyes and guides are also fitted during assembly)
- the work access holes plan
- the block arrangement handbook

Work Instruction Scheduling Work instruction scheduling includes preparation of weekly and daily schedules and a weekly meeting for integrated schedule tracking. Weekly and daily schedules are made for assembly, subassembly, and parts fabrication, using the same pattern as for preparing the monthly schedules. A weekly schedule orders work to

be performed over a two-week period and is updated every week. Sometimes a weekly schedule can be eliminated if the impact of changes is nominal and their effects can be controlled by annotations on a monthly schedule. Daily schedules are prepared for ordering work to be accomplished the next day and, of course, are updated daily. They are prepared by immediate or intermediate supervisors and serve to inform workers of their work assignments for the coming day.

An integrated schedule-tracking meeting is held each Friday afternoon to check progress of erection, assembly, subassembly, parts fabrication, outfitting, and painting by each process lane (work cell) and the progress of the mold loft. A representative from each process lane and the loft is required to attend to exchange information and to annotate progress achieved on the integrated schedule. As it is very important for continuing integration of the various types of work, feedback from these meetings is used to make adjustments in monthly, weekly, and daily schedules.

3 3 4. Man-hour Budgeting and Control *Man-hour Budgeting.* During basic planning, an original budget for the man-hours needed by the hull construction department is estimated. This budget is categorized to establish shop budgets using parameters based on normal past performances. The essential elements of this man-hour determination system are shown in Figure 7-31.

Man-hour Control. Budgeted and spent man-hours per unit time are both plotted on the same 10-workday report to facilitate their comparison. Evaluations of the differences are the bases for work load-leveling decisions. A field engineer oversees worker allocations made by supervisors on their daily schedules. The man-hour budget control imposed by a field engineer is based on normally performed rates of work, such as normal man-hours per subassembly welding length.

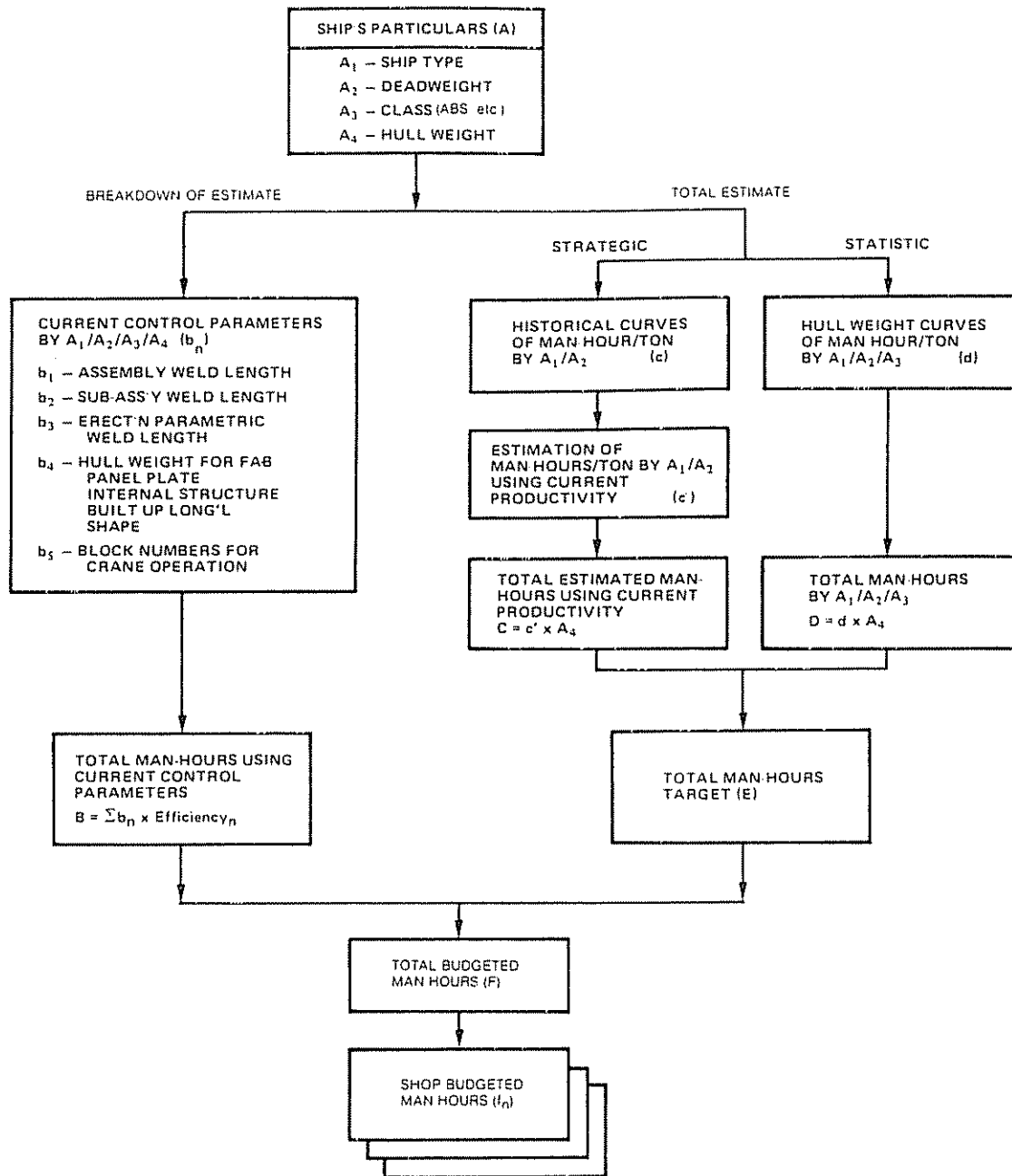


Fig 7-31 Man-hour budget determination system

As the design develops, more accurate information is constantly substituted for previously assessed characteristics such as assembly welding length, on which the control parameters are employed.

3.4 Shop-Level Planning and Scheduling

Each shop of the hull construction department is responsible for planning and engineering its own processes and for associated scheduling, material control, accuracy con-

trol, etc. Production engineers assigned to each shop ensure that all pertinent shop documents are consistent with the logic and principles of integrated ship production.

For receiving, storing, and issuing control, steel is requisitioned in relatively small lots to support block-by-block parts fabrication. Overstocking is inefficient because it commits capital and storage space that could be more productively employed. Also, overstocking generally increases man-hours spent for handling and causes misappropriations, with attendant risks of disrupting the parts fabrication and following processes.

Upon material receipt, control is maintained by storing standard sizes at designated places by size, or by parts fabrication sequence/block/process lane, and by issuing and transferring material by lot/day in accordance with issue orders which reference cutting plans. The need to facilitate material handling at the parts fabrication stages has priority over all other considerations.

3.4.1. Mold Loft Scheduling The schedule which controls the mold loft is organized by ship/block/day. Manning curves/block are determined from this schedule, which is based on normal performances. The mold loft guidance, prepared by a production engineer during working detail planning, explains details and other essentials for avoiding past inefficiencies and errors and further improving productivity.

Actual progress and man-hours spent are recorded each day to indicate completed work on the shop schedule and spent man-hours on the manning curve. When one is divided by the other, the quotient is an indicator of productivity (such as man-hours/block).

As the time allowed for design development and lofting is not excessive, expediting effort by the production engineer assigned responsibility for inputs to and outputs from the loft are always worthwhile. For this purpose, the mold loft and yard plan issue

advance curves are employed. These S-curves, plotted by number of sheets of yard plans versus time, are schedules which show the progress of yard plan receipts and processing by the loft. Expediting requires awareness that:

- overexpediting may cause loft errors which could snowball in succeeding work processes
- insufficient expediting could seriously disrupt compliance with coordinated schedules for integrated production

Accuracy Control. Most of the problems causing loft errors and accuracy variations are those which remain undetected until block assembly and erection. There, because of such problems, rework activities are greatly magnified. In a well-managed mold loft, process variations are usually too small to justify the application of classical accuracy control theory (see Chapter VIII). However, loft errors (mistakes, omissions, etc.) are of great concern, because they can be sleepers for untimely disruption. Error prevention measures such as the following are of utmost importance:

- a countercheck system by senior loftsmen following self-checks by loftsmen performing the work
- routine education and training
- clear mold loft instructions and work instruction plans prepared by production engineers
- written procedures for checking, recording, classifying, and statistically analyzing errors
- maintenance of loft defect lists and posting graphic representations of frequency of occurrence

3.4.2. Parts Fabrication Shop Scheduling. The parts fabrication shop schedule is drawn by process lane with reference to the erection and assembly master schedules. Start dates

for each process lane are staggered, as their rates of production are different and the parts needed for assembly must all be ready at the same time. For example, marking and cutting of parts which require bending are scheduled to start earlier than those processes for straight parts. Particular care is given to fix the lead times for fore and aft body parts which are to have complex shapes.

Further, the shop production engineer who prepares the schedule considers the need to maintain uniform work flows. For example, relatively small parts or those which require a disproportionate amount of time for intricate cutting (also parts requiring special beveling) are separated from the main work flow. Another technique for maintaining uniform work flow is to flame plane identical parallel parts required for several different blocks in succession rather than by block. This minimizes tooling changes, which is valuable since productivity of a flame planer depends largely on the number of times gas cutting tips are rearranged.

Material Control. The objective of in-process material control is to deliver all required finished parts just in time for subassembly or assembly. Follow-up is facilitated by providing a column on each hull parts list for check-off. This indicator of parts completion and sufficient material-handling resources is necessary for collecting parts for one block that have been distributed in cutting plans for several, in order to reduce scrap. In such cases, additional time must be allocated for collecting all parts needed by block.

Progress and Productivity. In addition to checking off completions on the hull parts list, annotations are entered on schedules. The weights of parts completed are accumulated daily, and spent man-hours are accumulated biweekly. This information is plotted on graphs for each ship as the weight of completed parts versus time, for progressing, and spent man-hours versus weight of completed parts, for assessing productivity.

3.4.3. *Subassembly Section.* Separation of subassembly work from assembly work makes sense, because subassemblies and blocks have significantly different work contents. This makes process flows impractical. Addressing subassemblies separately enables work to be considered in small increments that are very effective for work load leveling (providing constant rates of work). Other benefits include:

- improved productivity, because laying-out, fitting, welding, and distortion removal work is more accessible
- better welding quality, because more welding is performed downhand
- less material handling and administrative work during assembly, as fewer material items and less scaffolding are then required
- large facilities, such as heavy-capacity cranes and buildings with high ceilings and large doors needed for assembling blocks, are not occupied with work that can be performed elsewhere
- more opportunity to apply labor-saving devices (conveyors, automatic welders, and robots)

As many different subassemblies are required in varying quantities, the application of group technology provides the benefit of production line operations which are especially engineered for subassemblies. For example, after flat subassemblies are separated from curved subassemblies, their primary grouping is not by similarities in design. Instead, it is by work content.

When a group is large, it is scheduled for manufacture in a process flow. Groups which are small are jobbed, using resources that do not diminish support of the process flows. Examples of this are overtime, second shift, borrowing workers from the assembly section or erection shop, or the use of subcontractors.

A technique which further facilitates work load leveling is production of relatively

small weldments (assembled parts) as preparation for subassembly. Assembled parts (typically one or two brackets welded to a short L-shaped section) are manufactured in a process lane which is dedicated to just such work.

Scheduling. A schedule is prepared for each process lane in accordance with the assembly master schedule. Important considerations are separately addressing subassemblies of the same family (same problem area and work content) for continuous process flows, the time to be allocated between subassembly completion and block assembly and the limits of the subassembly storage areas, and work load leveling based on man-hours per welding lengths.

Material Control. Material control at first addresses receipt and organization of parts required for manufacturing subassemblies. Sufficient storage space is provided between the parts fabrication and subassembly areas for collecting and sequencing parts as required by subassembly schedules. As their efforts directly affect productivity, material handlers and the information prepared for them have to be well organized. Special provision on the hull parts lists facilitates annotations of the status of needed parts. The lists are also annotated to maintain the status of subassembly completions. The accuracy of such data is vital, as material handlers are required to collect, sort, and stow subassemblies for minimal periods in relatively little space.

Progress and Productivity. The progress of each process lane is checked daily for receipt on the parts list for each subassembly and completions on the subassembly schedule. As welding comprises the major work effort, a most useful productivity indicator for subassembly work is arc time per welder. Thus, production engineers strive to:

- increase welding length/hour/worker by enhancing worker skills and welding equipment

- extend the use of automatic and semi-automatic methods, such as gravity feed welding devices
- apply mechanical aids, such as for turning over or transferring subassemblies
- increase interchangeability of workers among all subassembly types of work, including material handling, fitting, welding, and fairing

To monitor the rate of change in productivity, performance indicators are plotted and posted at each subassembly flow lane. These are man-hours/subassembly weight and man-hours/welding length.

3.4.4. Block Assembly Section. Block assembly, the last process before hull erection, is initiated by material handlers who coordinate their collection of subassemblies with the arrival of parts for a panel on which a block is to be assembled. For organization of process flows, flat panel blocks, which require flat platens for their assembly, are separated from curved panel blocks, which require pin jigs. Separate process lanes are also organized for each of the other type blocks which impose different manufacturing problems and have widely varying work contents. Typically these include fore and aft body and engine room blocks.

Scheduling. Separate schedules are drawn for each process but are kept within restraints ordered by the assembly master schedule. The block assembly guidance and plan provide advance information on required stage sequences, welding lengths, need periods for outfitting, and the time that a crane is required at each stage. Thus, the field engineers are able to prepare a manning schedule for welding and a crane schedule for each assembly process lane.

Block Storing. Productivity of the hull construction department is greatly dependent on planning for storing blocks. Theoreti-

cally, the assembly of each block should be completed just in time to meet its scheduled erection date. This would preclude need for large land areas and would minimize work associated with transferring and supporting bulky and heavy blocks. It would also create more pressure to improve assembly processes until blocks were produced at the same rate that they are needed by the erection shop. However, production engineers also have to consider other factors and make tradeoffs. Considerations include:

- different quantities of required work (typically for hull construction: parts fabrication 10 percent, subassembly and assembly 50 percent, erection 40 percent)
- need to level load all shops
- authority to transfer workers between shops, assign overtime, and employ subcontractors
- costs for facilities (those for an erection dock and cranes are usually the most expensive)

The tradeoffs typically result in:

- building docks in which ships are rapidly erected
- enough land to accumulate 40 percent to 60 percent of the blocks required by ship, dependent on ship type and size before keel laying
- enough resources to complete the remaining blocks in time to sustain a smooth work flow during short erection periods (2.5 to 4 months, dependent on ship type and size)

Thus, planning for the storage of blocks is dynamic and requires the utmost discipline in scheduling. Necessarily, some land allocations made before keel laying for a specific ship are reallocated as blocks are erected, and as additional blocks are produced after keel

laying for the same ship, as well as for accumulating blocks before keel laying of additional ships. Other factors that production engineers must consider are the bulk of each block and actual block assembly progress as related to assembly schedules.

Material Control. Most subassemblies are of sufficient size to be readily located. However, because of their bulk, it is important to ensure delivery of subassemblies to the particular stages of the block assembly process lanes in planned assembly sequences. This transfer effort requires meticulous crane schedules and skilled material handlers to ensure that the schedules are faithfully implemented. Sufficient, not excessive, storage areas next to the stages where subassemblies are needed enhance efficiency.

Progress and Productivity. Welding dominates assembly just as it dominates subassembly. Assessment of the lengths to be welded is needed beforehand to allocate the required number of welders per day commensurate with schedule adherence. Just enough material handlers, fitters, and crane operators are allocated to avoid disrupting uniform welding work flow. Thus, continuing to improve block assembly productivity is dependent on continuous improvement of welding productivity and on providing the necessary support services, while minimizing the number of support workers.

Particularly regarding process flows organized for flat and curved block assembly, every effort is needed to avoid disrupting influences. If the assembly of one block stalls, work for all succeeding blocks and possibly for erection is adversely affected. Disruptive influences include:

- change orders
- failure to exploit statistical control of manufacturing
- manufacturing errors
- errors in allocating required durations, particularly for outfitting and painting

Changes in block assembly productivity are assessed by monitoring:

- block weight/unit time
- welding length/unit time
- total man-hours/welding length
- welder man-hours/welding length
- fitter man-hours/welding length

3.4.5. *Erection Shop.* The erection process finalizes hull construction work, and the erection schedule is the determinant of the hierarchy of schedules for preceding work (assembly, subassembly, and parts fabrication). Work is planned by zone for stage-by-stage implementation. The stages include:

- block erecting
- shipwrighting
- scaffold erecting

- main structure fitting
- main structure welding
- substructure fitting
- substructure welding
- on-board outfitting
- cleaning and painting
- internal visual inspection
- scaffold removing
- tank testing

Scheduling. Scheduling for hull erection is performed in conjunction with major detail planning (see Section 3.3.1). Additionally, effective erection scheduling requires that keel laying begin as soon as possible after launching a previous ship, and that there be careful coordination of scaffolding installations and removals with schedules for block erection, inspection, and painting.

4. Production Control

Production control is responsible for monitoring cost and schedule adherence while work is in progress. The production control organization is generally responsible for issuing man-hour budgets to be used to control the shipbuilding process and upon which progress will be judged. Progress relates actual work completed and actual man-hours spent. Consequently, there is need for evaluation which involves sorting, analyzing, and reorganizing performance data. These data are collected by control groups in order to monitor expended man-hours, production progress, and productivity, and to feed back system-oriented data for estimating future shipbuilding projects. For these purposes, it is sufficient to address only manpower among the product resources. This is because material is identified both by system and zone, and facilities and expenses are charged as overhead on direct material and manpower accounts. Thus, practical indices (see Figure 7-5) for monitor-

ing expended man-hours, progress, and productivity are sufficient

4.1 Man-hour Expenditures

The character of the manpower index (man-hours per unit time) is the same for the various control groups of work packages which apply to all work categories. Typical accumulations of such data are shown in Figures 7-32, 7-33, 7-34, and 7-35. The plotted curves indicate actual manpower costs but only apparent progress

4.2 Production Progress

As shown in Figure 7-5, the indices for production progress use different measures (weight, welding parameters, laid cable length, etc.) per unit time. Further, it is sometimes necessary to apply more than one index for each control group of work packages. Accumulations of such data as illustrated in Figure

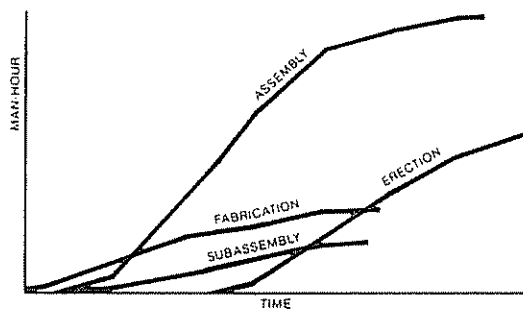


Fig 7-32. Manpower expenditures for hull construction

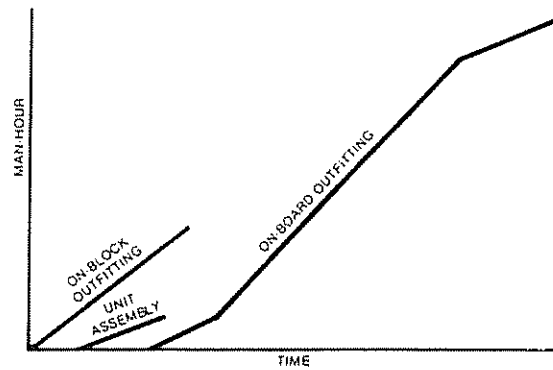


Fig 7-33. Manpower expenditures for machinery outfitting

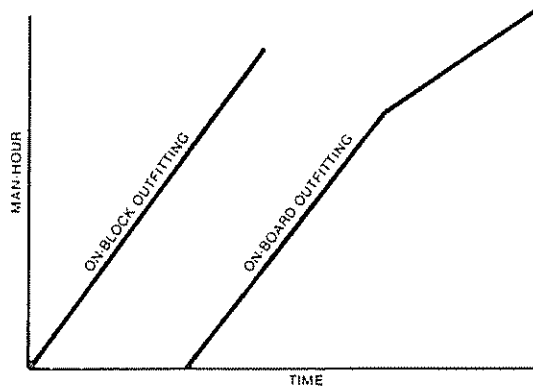


Fig 7-34. Manpower expenditures for electrical assembly (noncable)

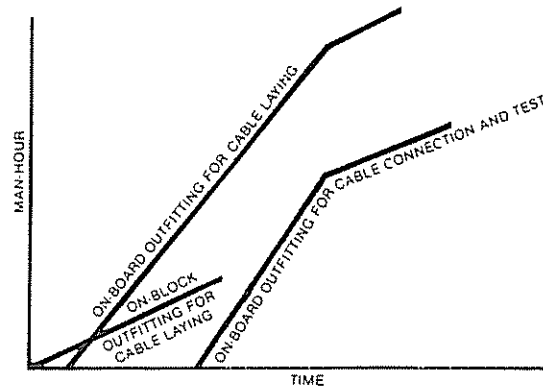


Fig 7-35. Manpower expenditures for electric cable assembly

7-36 reflect real progress. When compared to pertinent schedules, they are the bases for short-term adjustments, such as shifting workers or using overtime. When the manpower cost centers exactly match the shipyard or organization, as shown in Figure 7-37, it is practical to delegate such control to the managers of parts fabrication shops and assembly sections.

4.3. Productivity Indices

Productivity indices (see Figure 7-5) utilize both man-hours expended and the measures used for monitoring production progress (weight, welding parameters, laid cable length, etc.). Typical plots of such data are shown in Figures 7-38 through 7-42 relative to established standards of efficiency. Each of

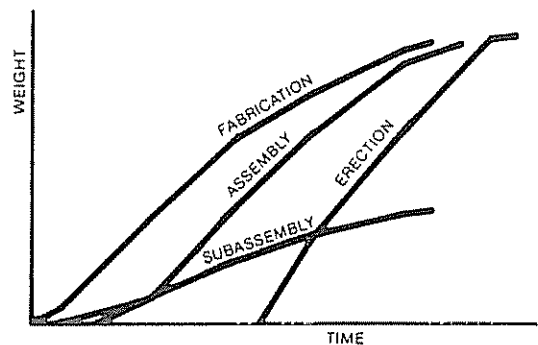


Fig 7-36. Production progress for hull construction

the latter is usually an average based upon the performance history associated with a specific control group of work packages. Any curve which appears above its efficiency ref-

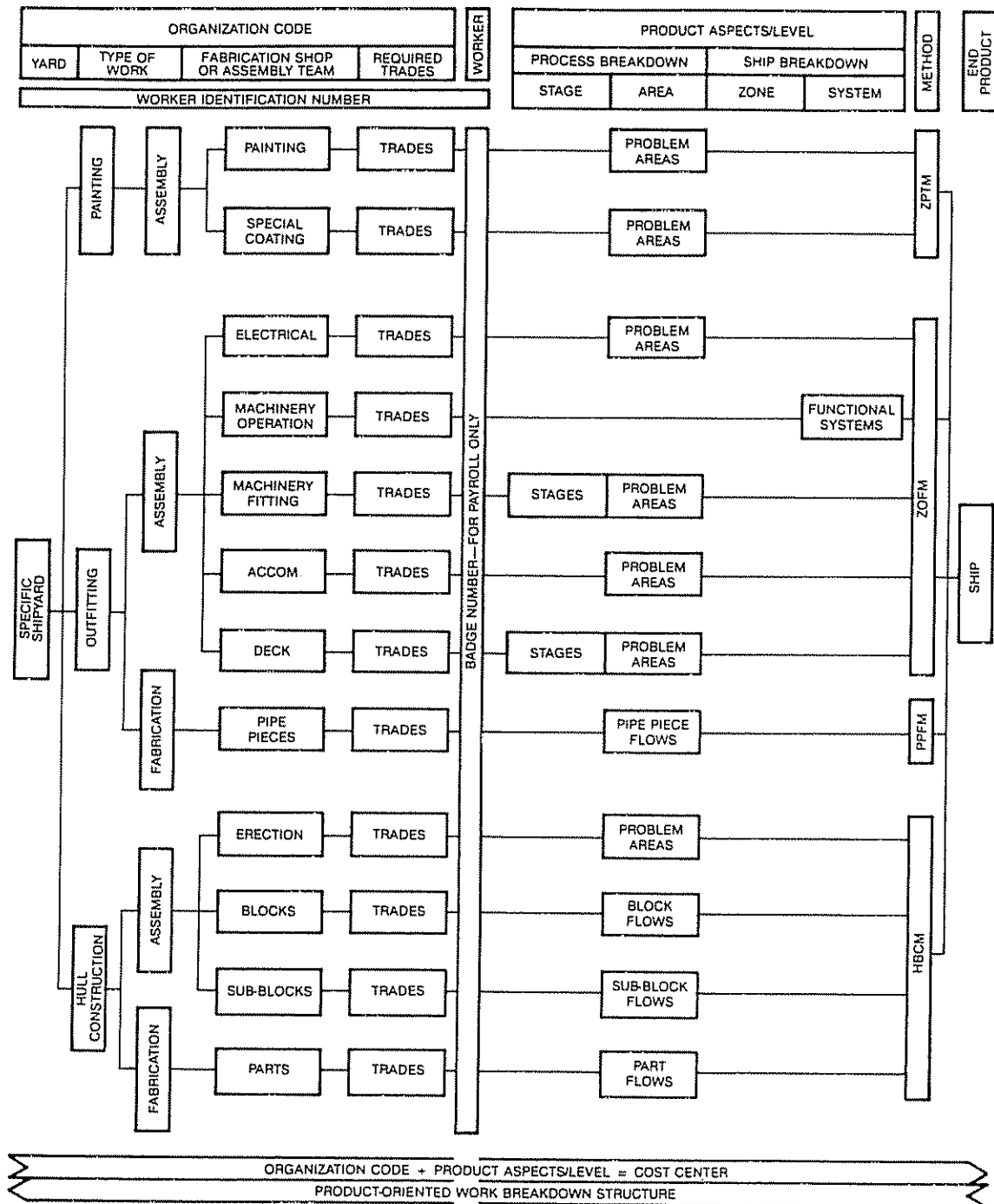


Fig. 7-37 Typical cost centers

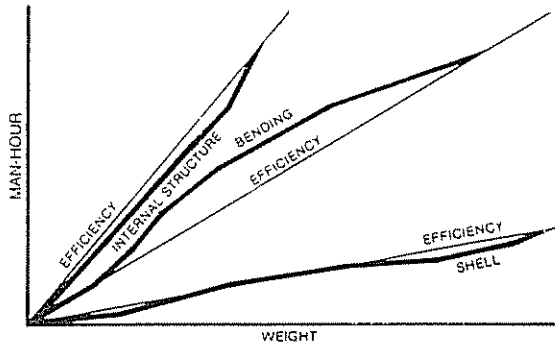


Fig 7-38. Productivity of parts fabrication

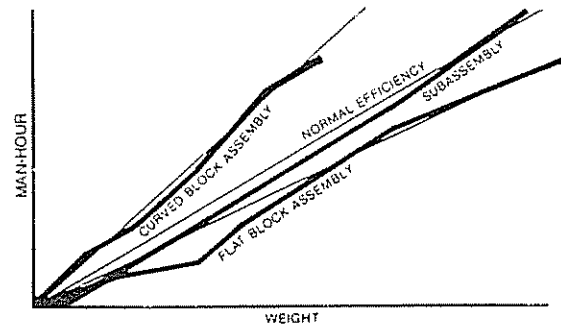


Fig 7-39. Productivity of subassembly and block assembly

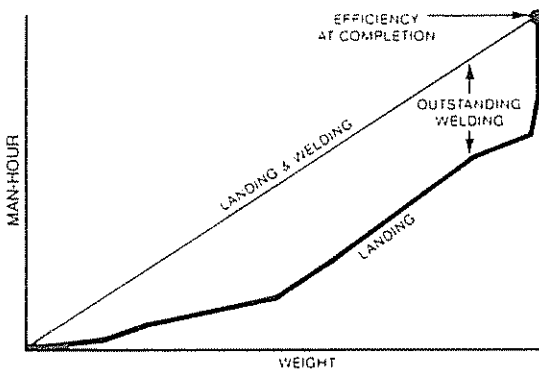


Fig 7-40. Productivity of erection

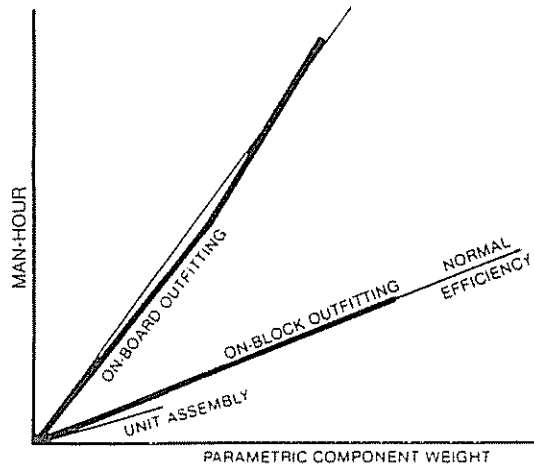


Fig 7-41. Productivity of machinery outfitting

erence indicates man-hour expenditures at an above-average rate.

Productivity evaluations can be simplified by a Productivity Control Group (PCG) concept. It eliminates consideration of specific product aspects. It is practical, provided that each PCG corresponds to a specific manpower control group and the same indices for manpower expenditures, progress, and productivity apply within each manufacturing level.

An example of a PCG is illustrated in Figure 7-43. Product aspects are disregarded, because work packages are planned so that their efficiency values, for normal productivity, fall within a specified allowable range.

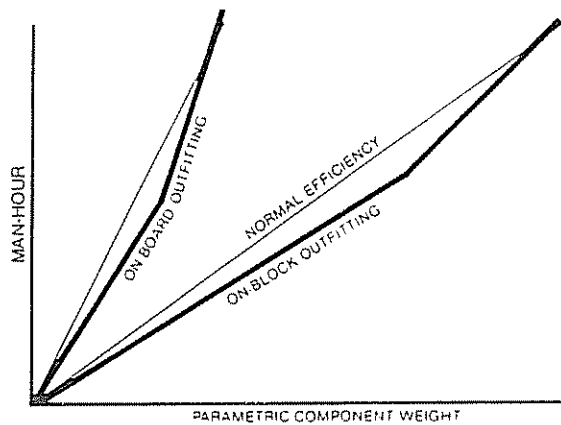


Fig 7-42. Productivity of electrical assembly (noncable)

by manufacturing level. The PCG concept is an example of the versatility of a product-oriented work breakdown structure. When unusual problems occur, such as during break-in of new facilities or overexpenditures of manpower, more control is applied by using the best-suited combination of product aspects. Conversely, during routine operations the simpler PCG approach is more practical.

4.4. Zone to System Transposition

The productivity indices are useful for transposing manpower expenditures for zone-oriented work to the system-by-system data needed for estimating. In PWBS, man-hour expenditures can be collected by different methods for grouping work packages, depending on the degree of control required. These vary from any combination of trade, manufacturing level, system, zone, problem area, and stage (see Figure 7-37) to a simple Productivity Control Group (see Figure 7-43).

Additionally, it is useful to separately address each material item for which there is no correlation between its weight and required fitting man-hours (a main engine, boiler, hatch cover, etc.). The fitting of each such "nonparametric" item is the subject of a separate work package. This permits the collection of man-hour expenditures by component, which is immediately identifiable with a system.

Thus, in consideration of the two sources of zone-oriented data, parametric and non-

parametric man-hours, the total man-hours apportioned to a system can be expressed by the formulas:

$$H_t = H_p + H_c$$

where

H_t = total man-hours

H_p = total parametric man-hours

H_c = total nonparametric man-hours

$$H_p = \sum e_i v_i = e_1 v_1 + e_2 v_2 + \dots$$

where

e = a productivity index for a control group of work packages

v = pertinent description of that part of a system included in a control group of work packages, e.g., assembly weight, length of weld, manufactured pieces, parametric component weight, laid cable length, etc. (Sv_i describes the entire system)

i = the number of work package control groups in which a system is represented

$$H_c = \sum h_j = h_1 + h_2 + \dots$$

where

h = man-hours for fitting a nonparametric component

j = the number of nonparametric components

5. Material Control

The relationship between design, planning, scheduling, and material control functions has been discussed previously in this chapter. Also, Chapter VI indicated the need for and requirements of material definition during the design stages. The information developed by designers provides the framework upon which other shipyard people build necessary

data to procure material for and produce a ship. The development of this framework inescapably involves planning decisions, such as definition of materials, construction details for parts fabrication and assembly, identification of zone boundaries, and designation of work stages. The concept that design and material definition are aspects of planning

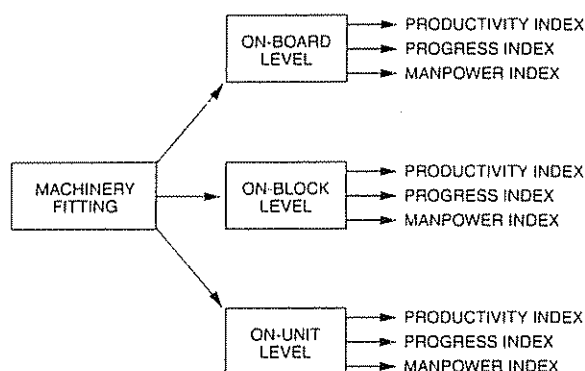


Fig 7-43. Productivity control group

is most important, because material orders must be placed strategically to facilitate just-in-time production.

Material control is one of the most important functions in applying and controlling group technology shipbuilding. In describing the pallet concept (see Chapter VI and Figure 6-2), the importance of material is stressed. The pallet is the entity that organizes detail planning and scheduling and is the driving force in production and production control. Since actual production work requires material, problems and delays in obtaining the proper material, at the proper time, in the proper location, present significant roadblocks to productivity. This realization motivates the emphasis on early material definition in the design cycle (see Figure 6-1), on the need for shipyard standardization in design and work processes, and on the use of the pallet concept to coordinate all aspects of the shipbuilding system. Control of material is the means of controlling production.

Material control includes authority for material requisitioning and direction over purchasing, expediting, warehousing, palletizing, and delivery to the work site. Material control converts design data, which is by ship/system/stage, into terms of material by material and delivery, to ensure meeting schedule

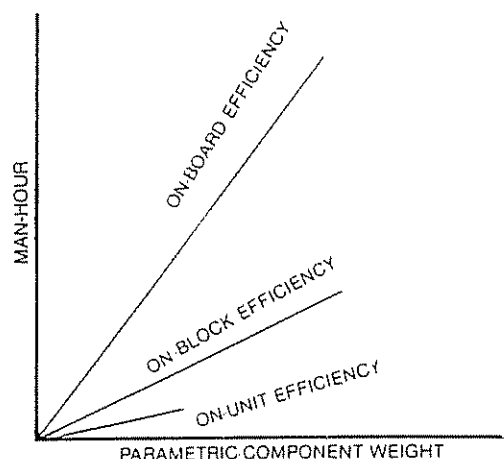
requirements while minimizing inventories and total cost.

5.1. Material Definition

Figure 7-44 illustrates the relationships of material to design, procurement, and production. Extensive information is required. All outfit items are first described in specifications coded with drawing (or purchase order) numbers which establish requirements. Next they are identified by a classification system. For the purposes of material procurement, production, and cost control, four code numbers are assigned. These are:

- material code number
- material cost classification number
- piece number
- work package number

For the same purposes, but specifically to identify the amount or volume of material needed to create a budget control list, they are further defined by actual (or, when necessary, estimated) weights and quantities (numbers of pieces, lengths, etc.). Finally, for grouping to facilitate material procurement by designating the required material procurement lanes, the following classifications are assigned:



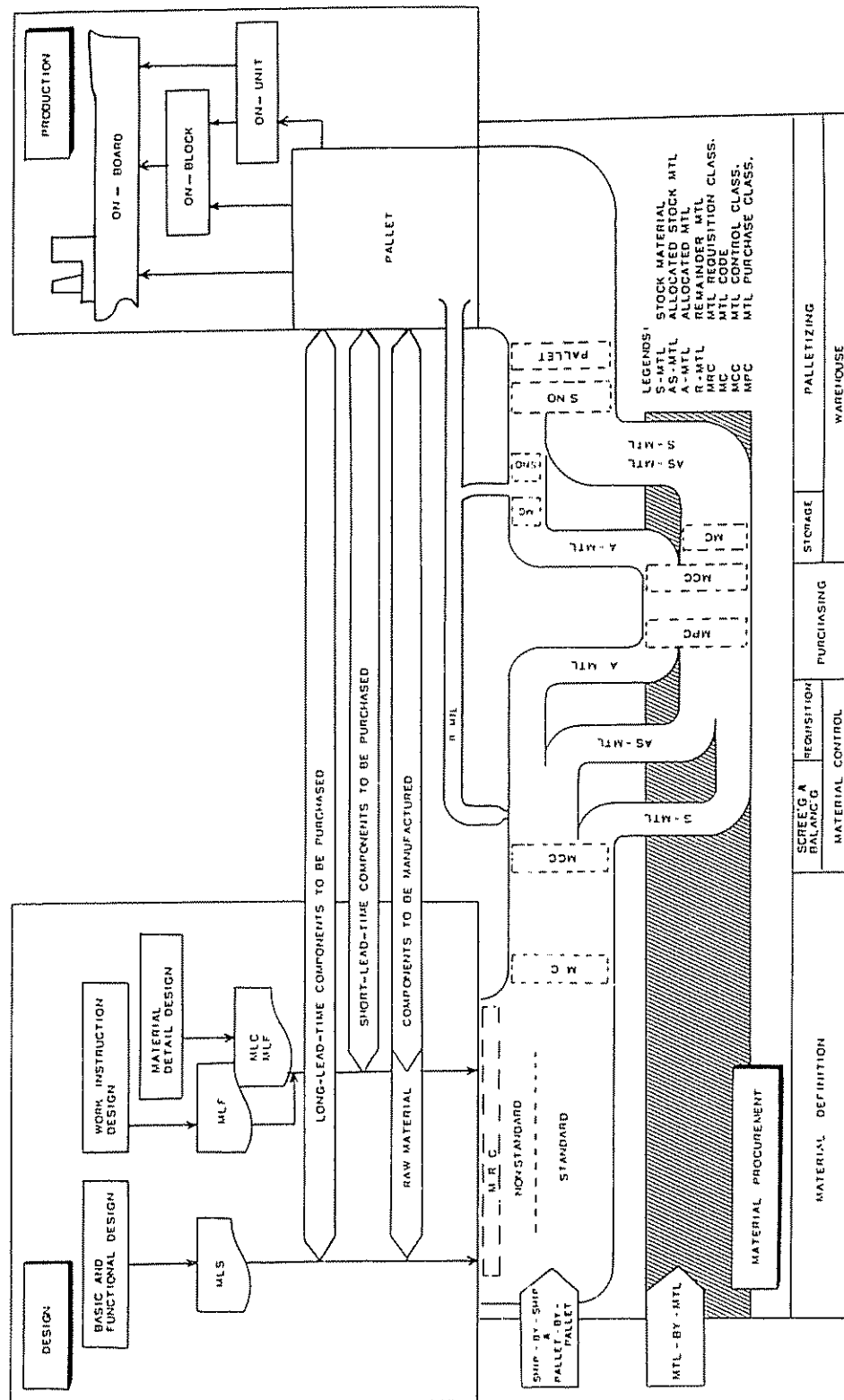


Fig. 7-44. Relationship of material to design, procurement, and production.

- material listing classification
- material requisition classification
- material control classification
- material purchasing classification

Actually, assignment of the latter two classifications is a material control function. However, there is benefit if they are at least tentatively assigned by designers. This enables designers to better prioritize their contributions for on-time material procurement. Subsequently, such classifications are confirmed or revised by the material control group. Provided with pertinent feedback, designers are able to adjust accordingly.

Concurrently with executing material definition responsibilities, designers must strive to comply with the material allocations assigned by the budget control list and its subsequent revisions. In order to do this, designers are primarily concerned with material quantities, as unit pieces are the responsibility of people assigned to purchasing. However, when the shipbuilding specifications permit selection from many material grades, such as for joinery work, designers cannot be unmindful of the costs. These combined responsibilities compose a relatively heavy burden. Standardization, with required classifications assigned to each material code beforehand, is the most practical way to compensate.

The flow of design information (see Figure 7-45) starts with the basic contract data and results in early information developed in forms which anticipate all material control requirements. It is important that designers know how critical their material-related work is to the success of an entire shipbuilding project.

Designers are required to supply sufficient and timely information necessary for procuring materials on time for manufacturing work in-house (and sometimes outside) and for assembly work on-unit, on-block, and on-board. Design scheduling must consider the lead times required between issue of ma-

terial specifications and starts of work by pallet. Figure 7-46 displays a typical critical path model showing the principal elements involved in material lead time.

Time is allocated for drawing approvals by the shipyard, owner, classification society, and other regulatory bodies. Although all requirements for approval are not shown on the critical path, frequently they have an effect. Thus, design scheduling, especially for functional design, must be done with particular regard for specific approvals required. The use of standardization is key to assuring timely development of material definition.

5.2 Material Classification and Procurement

Material is readily listed by system from diagrams and also by zone/problem area/stage from work instruction drawings. However, planning is not complete until each required item is assigned the following:

- material code number, which designates type, grade, size, etc (for identification in procurement)
- material cost classification number, which identifies a particular system and material family (for material cost control)
- piece number, which identifies, by unique serial number by system, where the item will appear (for identification in design)
- work package number, which identifies its end use by zone/problem area/stage of a specific level of a specific manufacturing method for a specific ship (for issue control)

To facilitate the procurement process and provide information in a form readily usable in production, a series of standard classifications of material is applied. The material lists from design (MLS, MLP, MLC, and MLF) are coded with material identification numbers

needed to facilitate computerization and the flow of information between shipyard functionaries. Whatever the coding system used, material can be classified into three basic categories:

- A — Allocated materials: These are purchased specifically against a contract requirement. Materials in this category include items such as a main engine, propeller, shafting, etc.
- AS — Allocated stock materials: These are purchased against a specific ship-building contract, based on the quantity

identified in design plus some margin added in material control.

- S — Stock materials: These are common to most vessels. They are requisitioned and purchased by the most economical quantity, based on historical usage data and design forecast.

Figure 7-47 further describes these classifications, which enhance effective material control by facilitating requisitioning directly from material lists produced by designers. Further, the requisitions themselves are categorized to speed the procurement process. This

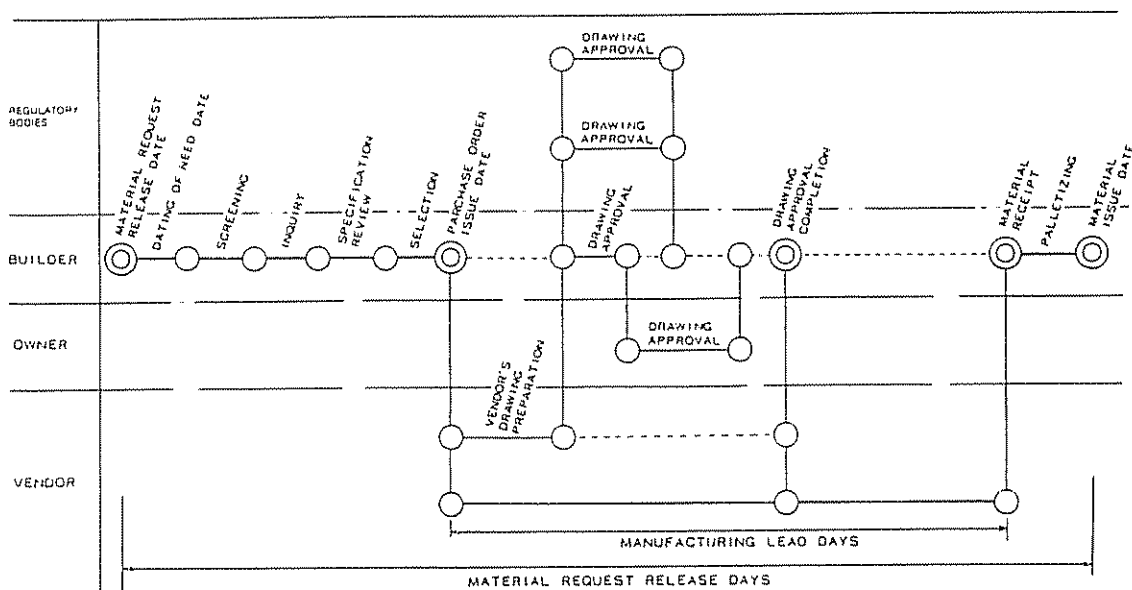


Fig 7-46. Critical path model of material lead time

CLASSIFICATION		MATERIAL EXAMPLES	STANDARDIZATION	USAGE RATE	QUANTITY TO BE ORDERED
A	ALLOCATED MATERIAL	MACHINERY SPECIAL EQUIPMENT & FITTINGS	GENERALLY NO	VARIABLE	BASED ON QUANTITY REQUIRED BY DESIGN DEPARTMENT
AS	ALLOCATED STOCK MATERIAL	VALVE, EXPANSION JOINT	YES	VARIABLE	BASED ON QUANTITY REQUIRED BY DESIGN DEPARTMENT WITH SOME MARGIN.
S	STOCK MATERIAL	FLANGE ELBOW, NUTS, & BOLTS	YES	CONSTANT	BASED ON STANDARD STOCK QUANTITY OR QUANTITY REQUIRED BY DESIGN DEPART- MENT WITH SOME MARGINS

Fig 7-47 Material control classifications

is done by specifying, on the material lists from design, the type of documents needed to initiate specific procurements. The three types are:

- T — This designation indicates an item which is a shipyard standard. As the buyers and customary suppliers maintain standard drawing files, no additional descriptive information is required.
- P — This designation identifies an item for which a purchase order specification must be prepared. Approvals of vendors' drawings are required. The P designator should be used in place of T if there is an owner or regulator requirement for a specification, even though the item is a shipyard standard. Because designers include the shipyard standard number in their material lists, buyers are informed that T-item purchasing procedures apply.
- D — This designator identifies materials to be manufactured in accordance with material detail design drawings prepared by the shipyard.

Figure 7-48 shows how the foregoing material codes differ in their definition content because of differences in:

- type of work: hull construction, outfitting, or painting
- usage frequency: for hull construction, shipbuilding grade versus special materials; for outfitting, materials commonly used in several systems, such as piping, access, ventilation, or raw materials versus materials used only in one system
- requisition classification: allocated, stock, allocated stock
- standardization: for hull construction, shipbuilding grade material is of

unique size by sketch (sketch size), of a standard size commonly used within a specific ship (standard within a ship), or of a standard size generally used in any type ship (standard)

Regarding standardization, any shipbuilding grade plate, angle, etc., for hull construction is sufficiently identified for procurement by material/grade/size. However, the same approach for all other materials would lead to voluminous purchase specifications. As shown in Figure 7-48, for outfitting and painting, materials designated "individual" are identified one by one with an appropriate full description for each. They are materials generally used in any type of ship. Other materials designated "family" are grouped in order to relate them by general characteristics. Except for two or three traits, a single description identifies all materials within a family.

Materials classified as "individual" are defined one by one in purchase specifications. Those classified as "family" are defined family by family, with unique traits separately defined. For example, certain valves are defined by family, and their specific sizes and/or design pressures are incorporated in purchase specifications.

Designating the system in each outfitting and painting material code, as shown in Figure 7-48, is useful because it facilitates standardization in material definition, cost classifications, etc. As also shown, it remains blank for common materials until their system designations are known.

Part and component codes respectively identify hull and outfit assembly zones which are not further subdivided. Thus, they apply to purchased interim products and those manufactured in-house or by a subcontractor.

As shown in Figure 7-48, composition of a ship piece number for hull construction is hierarchically configured as ship/block code, semiblock, or subblock/part code. Whenever a specific manufacturing level is bypassed, its

code is not included. Conversely, when a part is added as an exception, a grand-block joining code is incorporated.

The part code should contain, as a minimum, the parent block, system (bulkhead, deck, longitudinal, etc.), and unique serial number. As it facilitates parts fabrication shop planning, it is advisable to also include raw material type and part shape in the part code. Each part code appears in a hull block part list, a cutting plan, and a subassembly or assembly plan as appropriate. Thus, all "what," "where," "how," and "when" questions are anticipated by completely defined product aspects (system/zone/problem area/stage).

The elements of the ship piece number for outfitting are specified by ship/system/part no./component code (see Figure 7-48). The combined system code and the component code compose a material cost classification, as illustrated in Figure 7-49. The system code combined with a part number provides relative positions of pieces (finished interim

products only) identified in a system diagrammatic. Actual positions of pieces are as shown in each fitting drawing by zone/problem area/stage. Thus, all questions pertaining to outfitting are also anticipated by completely defined product aspects.

The identification codes presented in Figure 7-48 and described in the foregoing permit each material item to be assigned to both a system-oriented and a zone-oriented material control group. A work package number is used for zone-oriented material control during planning, scheduling, execution, and evaluation. A material cost classification number controls the same material by system for evaluation, estimating, and planning. The combined use of material code and a ship piece number permits transformations from zone-oriented to system-oriented data and vice versa.

The major steps in the development of requisitions are shown in Figure 7-50. The major goals of the requisitioning process are to:

MATERIAL IDENTIFICATION FOR PROCUREMENT					MATERIAL IDENTIFICATION FOR DESIGN & PRODUCTION
WORK TYPE	COMMONNESS	REQUISITION CLASSIFICATION	STANDARDIZATION	MATERIAL CODE	SHIP PIECE NO
HULL CONSTRUCTION MATERIAL	SHIPBUILDING GRADE	AS	SKETCH SIZE	MATERIAL/GRADE/SIZE	SHIPBLOCK, SEMIBLOCK OR SUB-BLOCK/PART CODE
			STANDARD WITHIN A SHIP		
			STANDARD		
	OTHER	SAME AS OUTFITTING			
OUTFITTING & PAINTING MATERIAL	COMMON WITHIN SHIP	AS&S	INDIVIDUAL	BLANK/FULL DESCRIPTION	SHIP/SYSTEM/PART NO./COMPONENT CODE (FOR OUTFITTING ONLY)
			FAMILY	NIL	
		A	INDIVIDUAL	BLANK/FULL DESCRIPTION	
			FAMILY	BLANK/FULL DESCRIPTION	
	UNCOMMON WITHIN SHIP	AS&S	INDIVIDUAL	SYSTEM/FULL DESCRIPTION	
			FAMILY	NIL	
		A	INDIVIDUAL	SYSTEM/FULL DESCRIPTION	
			FAMILY	SYSTEM/FAMILY DESCRIPTION	

Fig 7-48. Material control identification codes

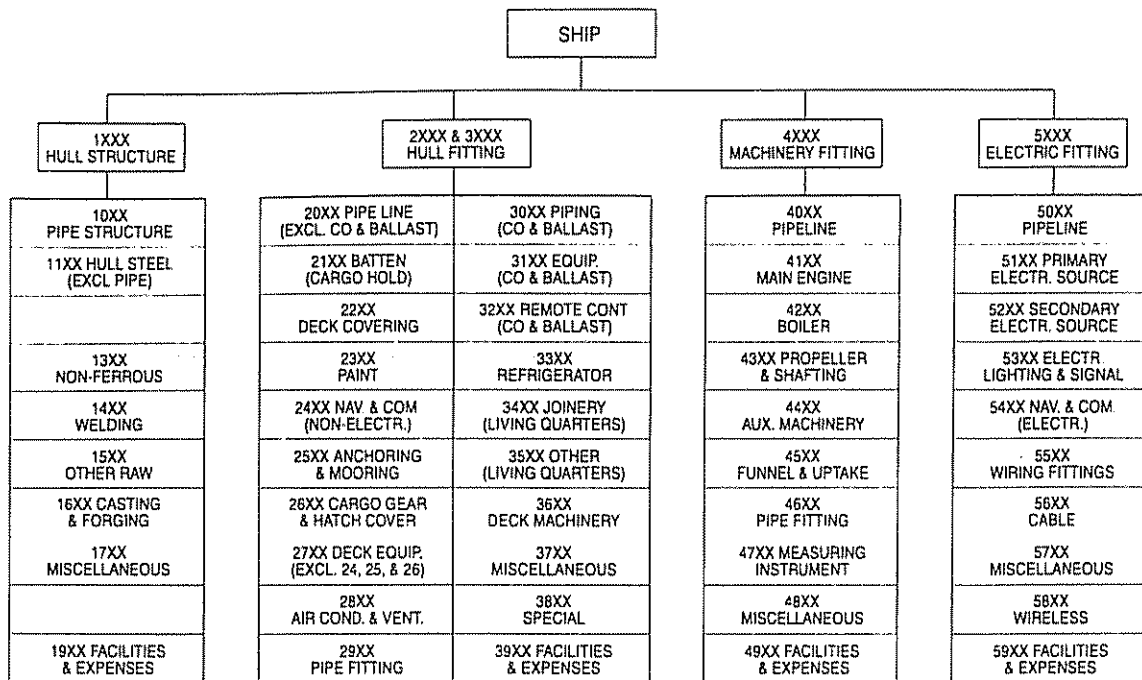


Fig 7-49. Structure for material cost classification

- convert from design data to procurement specifications
- convert from data by ship/system/stage to specification by material/delivery date
- plan material procurement on schedule
- minimize stocked material

Purchasing effectiveness can be enhanced by the use of long-term agreements with subcontractors. The rationalization considers the total cost of a particular component in terms of quality, timely delivery, design standardization, material storage, material handling, installation standardization, and testing. Often a particular component is higher in price from one manufacturer than another, but the total cost is reduced because of savings of man-hours, facilities, and elapsed time required for manufacture or assembly. Shipbuilders are generally alert to this and adequately evaluate total costs associated with high-priced items, such as a main engine, dur-

ing the basic and functional design (pre-MLS and MLS) stages.

It is also very important during the detail design (MLF) stage to watch for low-priced items that could precipitate high installation costs if they are not available for a planned work zone and work stage. Generally, they are short-lead-time materials for which purchasing is initiated after they appear on an MLF. The unit price alone does not fully describe the importance of an item to the assembly process.

The use of standard components enhances the potential for overall shipyard savings. However, it is essential for the successful application of standards that they apply to high-quality materials. This is particularly true for machinery items from manufacturers' catalogs that are listed as shipyard standards. Owners need guarantees about performance, parts availability, service, etc. Standards apply not only to raw materials and items such as valves and fittings, but also to

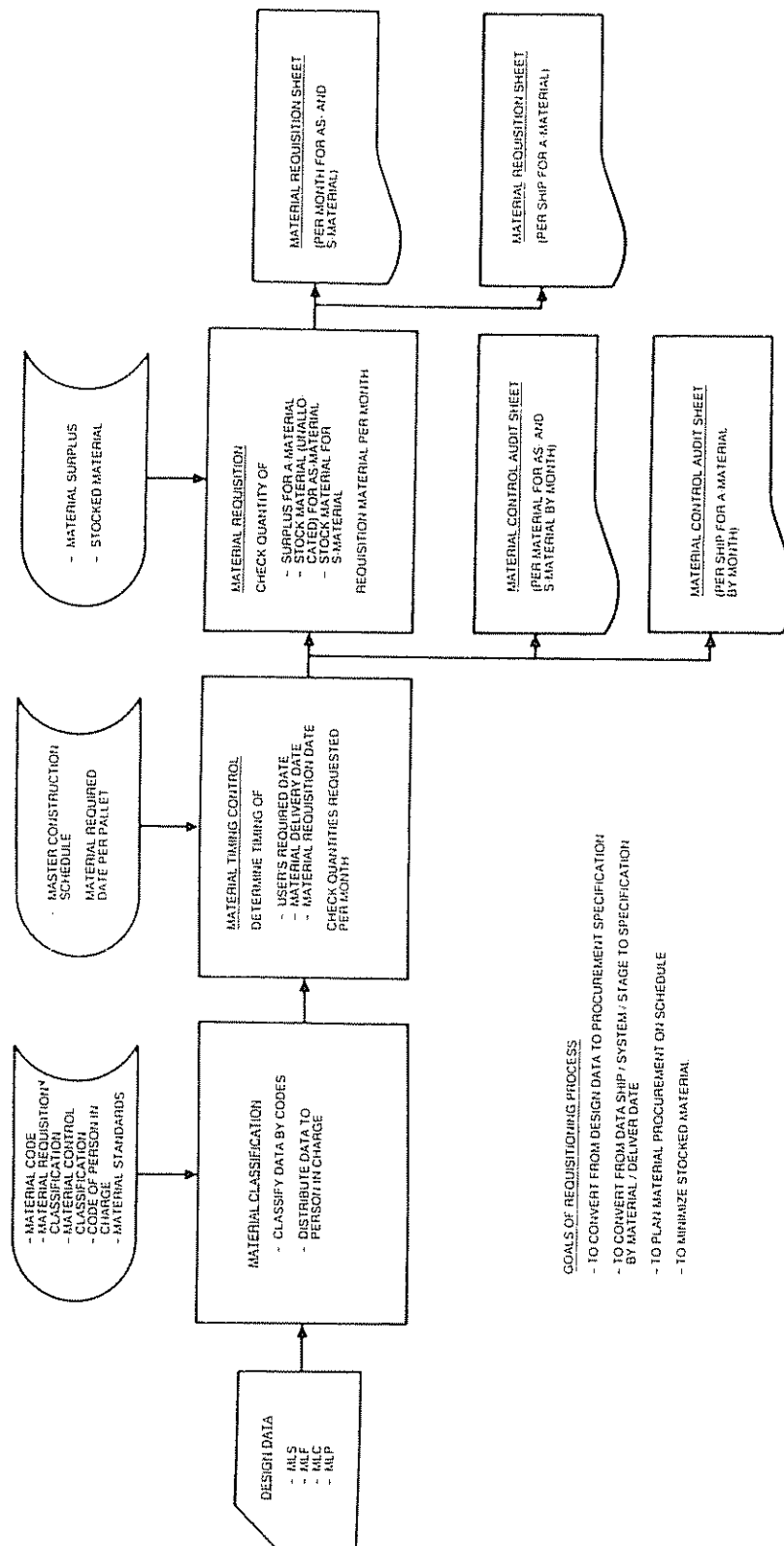


Fig. 7-50. Functional flow of the requisition process.

fabricated components such as hatch covers, ladders, gratings, miscellaneous tanks, and other small assemblies. Subcontracting for these items permits a shipyard to take advantage of skilled specialists who are qualified in their manufacture. This is another application of group technology.

Subcontracting reduces a shipyard's administrative burden in terms of purchasing, warehousing, inventory control, material handling, special tooling, and, more importantly, need to maintain and administer factories for manufacturing such components. Prudent subcontracting also takes advantage of a vendor's lower overhead costs for manufacture of small assemblies and permits concentration of a shipyard's resources on assembly of ships.

By identifying components on the material lists from design as T, P, or D (standard, specification, or drawing, respectively), purchasing people can readily determine the type of procurement required. Components identified as D are eligible for subcontracting. To acquire additional benefit, a shipyard can utilize its usually greater buying power and furnish certain materials to subcontractors. For example, manufacturing drawings, material lists, and material for a subcontracted item can be furnished by the shipyard. Other assistance, such as special tools or QA inspectors, might be furnished if needed for a new product. These close relationships encourage subcontractors to locate near shipyards and encourage shipbuilders to continue their growing tendency to use open-end purchase orders to fewer subcontractors as a means for improving productivity.

The capability to subcontract wisely is enhanced by the preparation of MLP and MLC during design. Each lists the raw materials required for a component identified as D. The relationships of such raw materials to a ship's functional system are in an MLS. Thus, purchasing people have ready identification not only of the components which can

be subcontracted but of the raw materials required for their manufacture.

The use of standards also enhances opportunities for long-term agreements with vendors for the purchase of other materials identified as T or P. There is much potential benefit. Some vendors will maintain inventories which minimize a shipyard's investment and contribute to improved cash flow. Long-term agreements could introduce not-other-wise-obtainable price breaks based upon volume. Further, it is generally accepted that purchasing administration costs can be reduced considerably by amending existing purchase orders rather than issuing new ones. In the United States, long-term agreements are made when a shipyard has orders for several ships of the same design. The use of a greater number of standard components increases the potential for long-term agreements for materials needed to construct different ships. Regardless of the level of standardization, the identification of materials as T, P, or D during design can significantly improve a purchasing department's ability to support zone outfitting.

To appreciate the full impact of standards, it is necessary to appreciate the entire management cycle, because every management function benefits from the use of standards. Decisions made in forecasting, planning, scheduling, and production are controlled by information both from previous steps and from feedback obtained from subsequent steps. Standards provide an opportunity for common understanding and improved communications among shipyard functionaries. Standards benefit the estimating, scheduling, and accounting functions by providing simplified, quality information that facilitates prediction, implementation, and evaluation. But there is much greater potential benefit in planning, particularly for design and material definition, and in production. Figure 7-51 shows a methodology for classifying stan-

Classification of Standards				Nos
IS	SO	Material Standards	Common components	600
			Hull fittings	600
			Machinery fittings	200
			Electric fittings	200
	Sub-total			1,600
	SOT	Design process standard		
Prod. engineering process standards			100	
Inspection process standard			200	
Sub-total			1,400	
SD	Machinery drawings			1,200
	Component and fitting, standard drawings			350
	Other guidance drawings			350
	Sub-total			1,900
Grand total				4,900

Fig. 7-51 Typical classification standards.

dards. The quantities shown are from a corporation which operates five yards for building ships of various types and sizes from 15,000 dwt to 500,000 dwt. This organization facilitates the cataloging and coordination of various types. Basic standards (IS) are those that must be closely followed by design and production. Standard drawings (SD) serve as guidance, allowing some flexibility to meet individual requirements. Standards also provide opportunities for saving man-hours, maintaining high quality, and simplifying computerization.

Some shipbuilders have extended the use of standards to modules of arrangements of various components. These "design modules" are intentionally general in nature so that they may be reapplied in different ship sizes and types. They also anticipate different customer needs and therefore allow some flexibility in application.

Further refinements have produced interim products for which the bulk of the planning data on file is immediately available for reuse. This includes diagrammatics, composites, MLP, MLC, MLF, material detail design, and work instruction drawings.

Another important aspect is the incorporation of machinery selected from manufac-

turers' catalogs. Each such machinery item is "approved" when it is designated as a shipyard standard. Needed vendor-furnished information is therefore already on hand and the time-consuming vendor drawing approval cycle is eliminated from the procurement process.

The MLS, MLP, MLC, and MLF are readily identifiable material requirement formats for support of material control and production. Materials on an MLS are ultimately incorporated on an MLF, either directly or as a component of something custom-manufactured. Similarly, materials on MLP and MLC are listed in their new identities as custom-manufactured items on an MLF. Thus, an MLF includes all outfit materials needed for a planned interim product—the pallet needed to outfit a unit, outfit a block, or outfit a discrete amount on-board. A pallet is a group of outfit materials necessary to perform a defined increment of work which is identified by an MLF. The pallet name is the MLF number.

Such organization permits sorting and collating in a manner that enhances material, schedule, and cost control. During the early design phases, identification of all pallets will not be known. The procurement process begins early, using MLS, and as the design develops, material is associated with specific pallets. Thus, as the MLFs evolve, procurement information is refined. Figure 7-52 illustrates the relationships of the material lists to design and to material procurement aspects. Since it is disruptive for designers to have to reorient themselves to what they did before, managers should assign high priorities to computer applications for continuously updating material lists. Maintenance of material lists is perhaps the most important computer application.

Functional design proceeds in the context of initial zones, which are subdivided into purchasing zones. Each of the latter is sched-

uled to create a basic outfit sequence for preparation of diagrammatics and their material lists (MLS). As planning continues, detail design drawings and the breakdown of work to pallets proceed simultaneously. A specific work stage and a specific work zone are depicted on each work instruction drawing (see Figure 7-53). Subsequently pallets are scheduled. This process is a refinement of the overall schedule, because the planning addresses smaller increments. Since the material requirements are contained first in an MLS, and then in material lists by pallet (MLF), the procurement data are refined as well. If the shipyard is building a vessel which is very similar in configuration to previously built vessels, pallets will be defined almost simultaneously with the new zone definitions. This enhances both the speed and accuracy of informational support needed for overlapping design, material control, and production. Thus, the total shipbuilding system incorporates similar concepts applied to work organization, design, planning and scheduling, and material control.

5.3. Warehousing and Palletizing

The warehousing function is directed by material control. It receives and stores material until an order is issued for its palletizing and delivery to the work site. The flow of information for warehousing and palletizing is illustrated in Figure 7-54. The goals of warehousing are to maintain accurate count and physical control of materials while minimizing handling and storage costs. The inventory process is aided by the identification codes utilized for materials definition in the design stage. Coding and standardization of materials permits the same commodities for different contracts and hulls to be stored in common locations. This is a recognized cost-saving measure in warehousing, provided there is adequate record keeping. There has to be clear assignment of responsibilities for all warehouse transactions. Accurate inven-

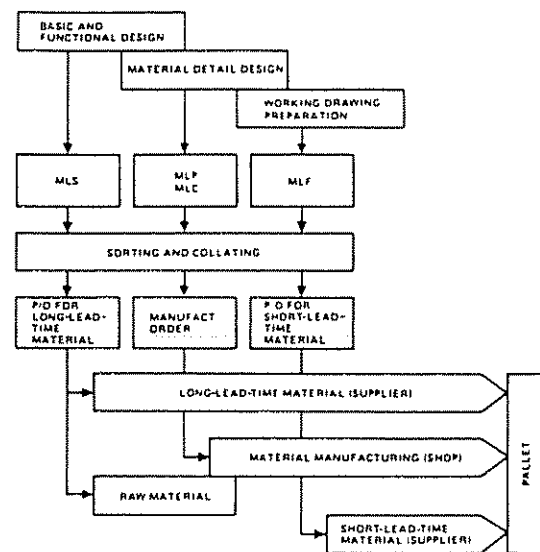


Fig. 7-52 Relationship of material lists to design and procurement.

tory records are essential for support of zone outfitting.

Warehousing also includes the combining of materials, stored by material code number, into pallets for delivery to the work site. Palletizing is the act of collecting a group of materials together to match an MLF. When a pallet issue order is received, material must be taken from storage to a kitting center where it is placed in one or more containers for delivery as a pallet (see Figure 7-55). The kitting center and the pallets themselves may be conceptual, in that a large item may be delivered directly from a subcontractor's shop, while several other components assigned to the same pallet may be separately transported to the work site in one or more containers (see Figure 7-56). It is also common practice to locate the kitting center adjacent to or within the physical perimeter of the shop which supplies the material being palletized. For example, pipe piece kitting is usually accomplished within the pipe shop by pipe shop personnel. The essential point is that final responsibility for palletizing be given to a single organization (the warehouse division).

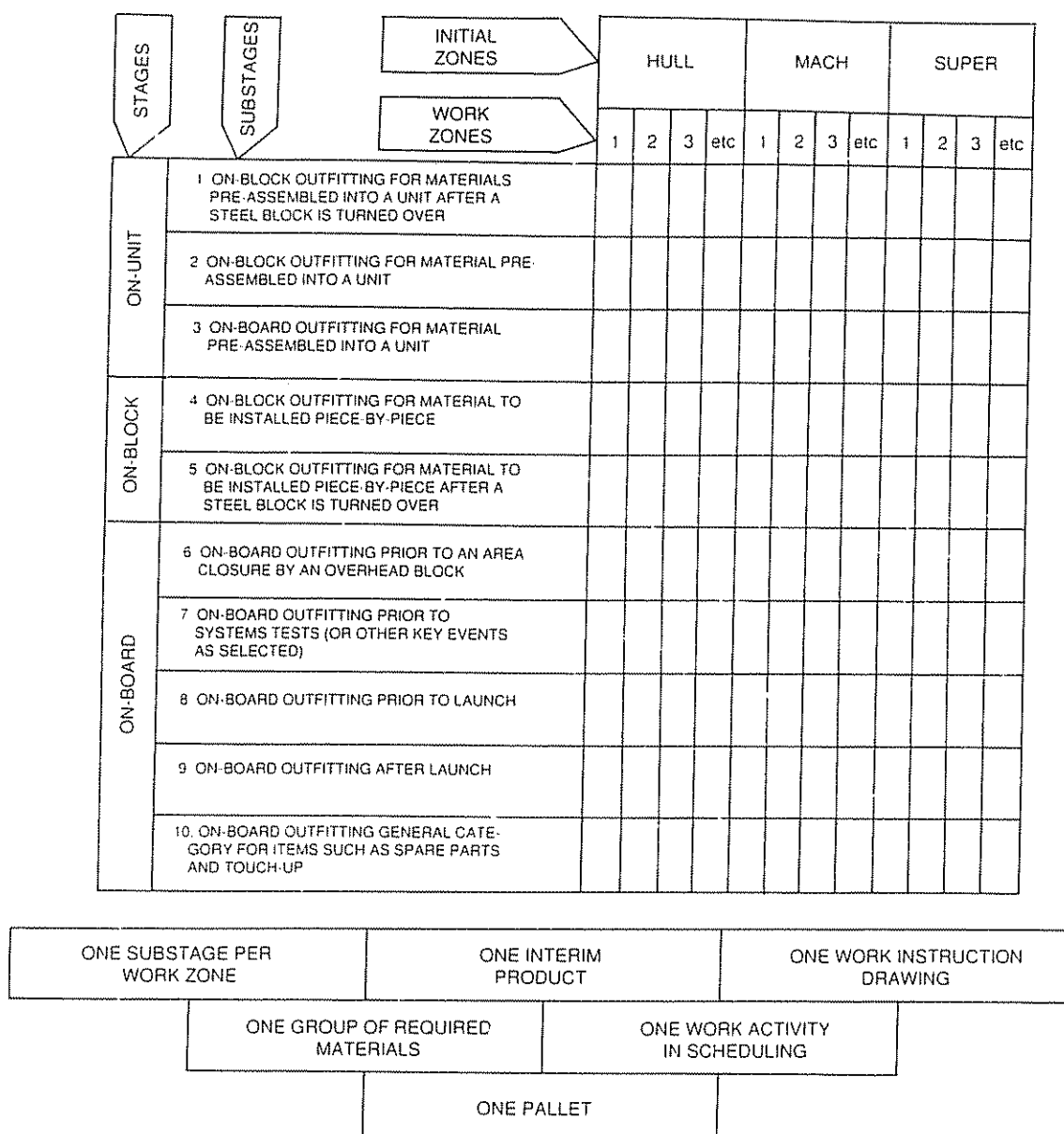


Fig. 7-53 Typical breakdown of work to pallets.

In order to release the materials at the proper time and deliver them to the appropriate place, a pallet issue order must be made sufficiently in advance to allow enough time for palletizing. Should quantities be insufficient to marshal all materials for a specific MLF, the individual in charge must inform procurement people that expediting action is required and notify control people, since they

may wish to adjust the applicable planning and/or schedule to compensate.

The palletizing flow is illustrated in Figure 7-57. Whatever numbering schemes or inventory methods are employed, resources, particularly people, for warehousing and palletizing must be enough to support the production effort. Nominal overcapacity of such resources may be prudent.

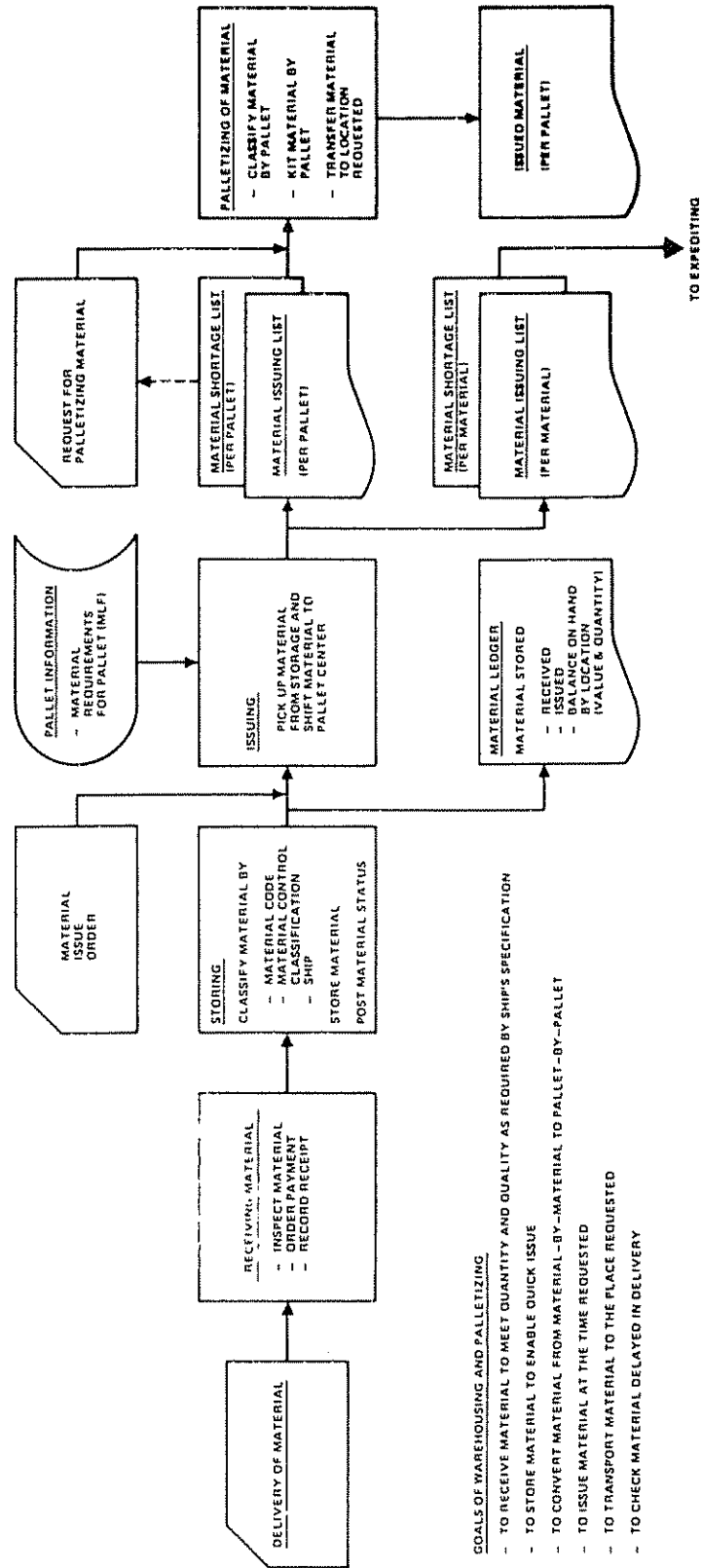


Fig. 7-54. Functional flow of warehousing and palletizing processes.

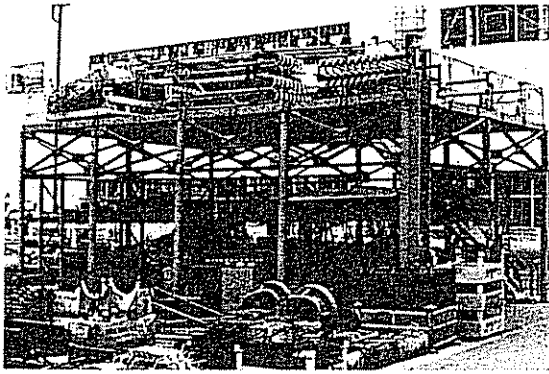


Fig. 7-55(a)

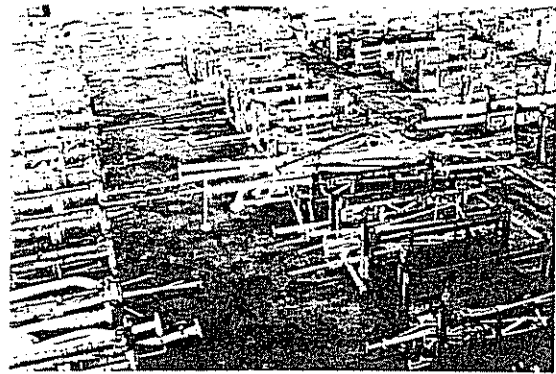


Fig 7-55(b)

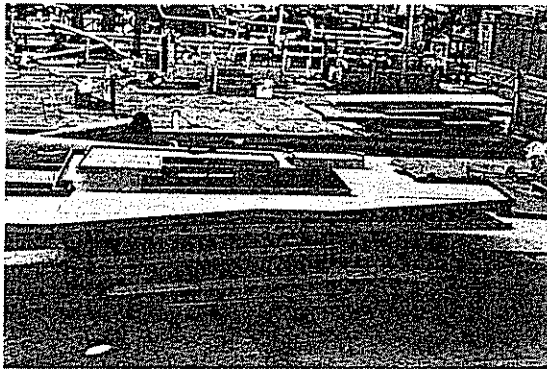


Fig 7-56

Fig. 7-55(a) Pallets stored outdoors Fig. 7-55(b) Pallets stored outdoors. Fig. 7-56 Subcontractor deliveries treated like pallets.

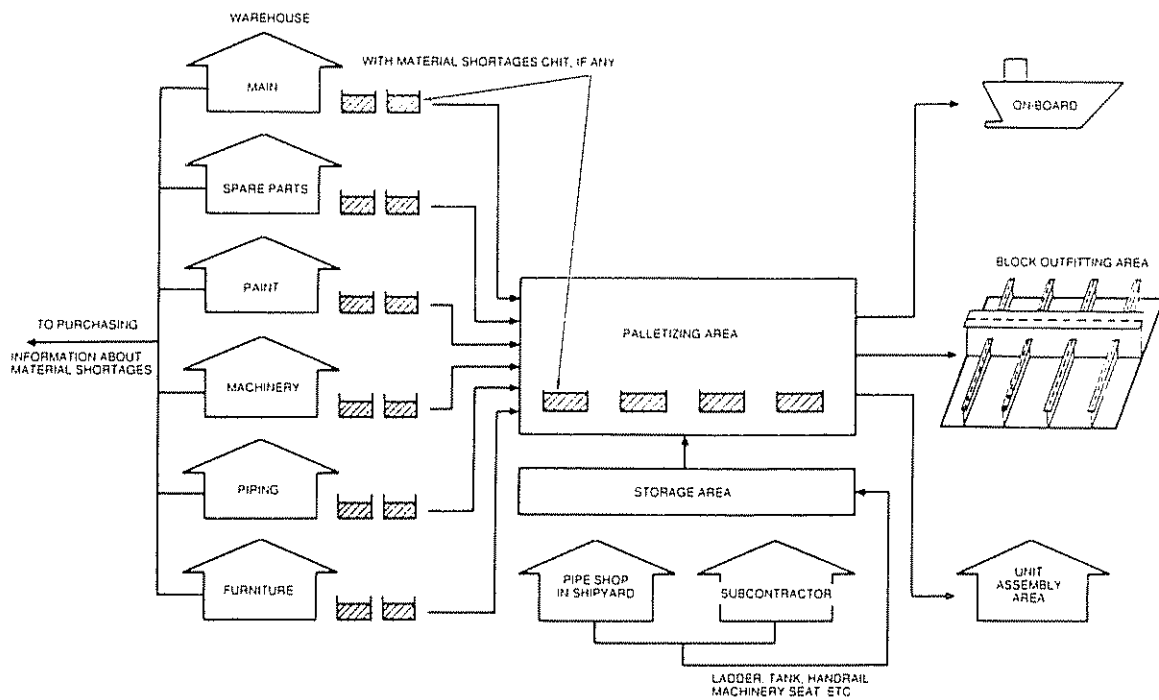


Fig. 7-57 Palletizing flow for material issue

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ACCURACY CONTROL

1. Introduction

A shipbuilding system based on group technology, using a product-oriented work breakdown structure and integrated hull construction, outfitting, and painting, requires that accuracy be controlled. Otherwise, work in succeeding stages of production is adversely affected by inaccurate interim products. Consequently, a system is needed to control the accuracy of interim products. Although the justification for such a system may initially be the need to monitor the construction of interim products to minimize delays and rework during erection, an accuracy control system is considerably more than this. When fully operational, accuracy control forms a major part of the total shipbuilding system. It involves the regulation of accuracy as a management technique for improving the productivity of the entire shipbuilding system by focusing attention on individual areas where improvements offer significant benefits. It also provides the means for monitoring work by individual work process or problem area. Additionally, a fully implemented accuracy control system establishes a quantitative feedback loop between production and planning, design, and engineering.

Accuracy control is defined as "the use of statistical techniques to monitor, control and continuously improve shipbuilding design de-

tails, planning, and work methods so as to maximize productivity."

The use of statistical techniques is an essential element in an accuracy control system. These techniques were developed during the 1940s and are described in the technical literature as "statistical quality control." In the context of shipbuilding, accuracy control should not be confused with quality assurance (see Chapter IV, Section 6). Accuracy control is the *regulation* of accuracy in order to maximize productivity. This regulation involves a tradeoff between better accuracy (and the subsequent improvement in succeeding assembly and erection processes) and the cost to achieve such accuracy [1].

1.1. Statistical Principles

Statistical analysis as applied in accuracy control is based upon the observation that there is no such thing as absolute accuracy (repeatability). No matter how precise workers try to be during a specific work process, variations from specified dimensions are always anticipated and measurable. Thus, accuracy exists only in terms of usually achieved ranges. Working with ranges of variations is crucial for production control and for achieving specified end product accuracy. Note that this discussion is primarily concerned with

variations and not errors. Errors are acts that through ignorance, deficiency, or accident cause departures from specified dimensions. They do not ordinarily occur. Accuracy control deals with variations that occur in the course of normal operations.

Variations in a work process are the result of the capability of the work process, including workers, machines and tools, materials, and procedures. Dimensional variations occur in any work process as a result of common and special causes. Common cause variation in a work process is the normal chance or random variation common to the process. It is the result of the production system, including raw materials, incoming parts or interim products, tools and machinery, worker training, work environment, etc. Variations due to common causes cannot be altered without altering the work process or the system that controls the work process. Reducing common cause variations thus becomes the prerogative of management. In essence, common causes are common to a whole group of workers and belong to the system. These variations are defined as being the result of common causes or causes common to the process capability. [2]

Errors, as defined above, are the result of special causes, or problems not common to the process. Special causes of variation are causes specific to a certain worker or machine. They represent a departure from previous conditions and performance. These causes should be identified and removed as a regular part of monitoring a work process. Special causes can often be corrected by the work force.

Any repeatable work process (consistent in facilities and worker skills) produces products that have variations in characteristics. For example, fabricated flat bars will exhibit variations from design dimensions. These variations, when plotted by the number of times they occur, approximate a normal distribution (see Figure 8-1). Two parameters

describe the relative shape of a normal distribution (N). They are:

- mean, $\bar{x}$, the arithmetical average of variations in a sample, which describes the central tendency of the distribution
- standard deviation, σ , which classes the sizes of variations from the mean value by their frequencies of occurrence, and thus is a measure of the relative scatter of points around the mean

For a normal distribution, 67 percent of the values fall within one standard deviation of the mean, 95 percent fall within two standard deviations, 99.7 percent fall within three standard deviations, and so on. Both parameters are obtainable from mathematical formulas.

Note that in the remainder of this chapter, discussion centers on sampling from normal distributions. The normal distribution of samples from a normally distributed population is described by the sample mean, $\bar{x}$, and the sample standard deviation, σ , as described above.

Similar considerations can be applied to each work process. Thus, spacings between longitudinals will vary, and another normal distribution having its own mean value and standard deviation applies (see Figure 8-2). Whether the variations in both flat bar

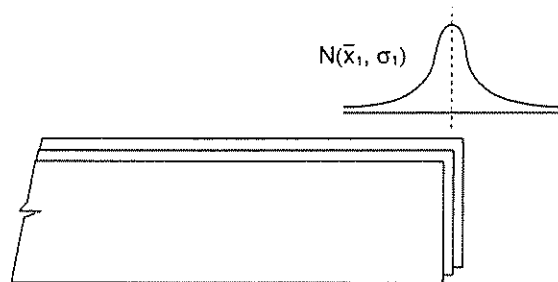


Fig. 8-1 Normal distribution of variation from design dimension of cut flat bars.

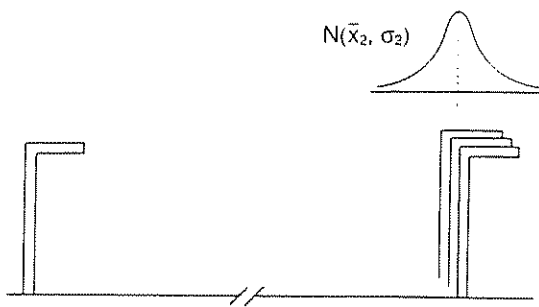


Fig 8-2 Normal distribution of longitudinal spacing

lengths and longitudinal spacings impose requirements for rework depends upon their merger during a later assembly process

1.1.1 Control Charts. The most common tool used in statistical quality control is the Shewhart control chart. Control charts apply the concept of expected and measurable variation in work processes and are used to distinguish between common cause variations and special cause errors. When only common cause variations are detected, the process is operating normally and requires no adjustment. Should special cause variations be found, however, investigation and identification of these causes is required to eliminate them and return the process to normal performance.

The control charts, a related set of one $\bar{x}$ and one R chart, are plots of the mean ($\bar{x}$) and range (R) of random samples of measurements from a specific work process over time (see Figure 8-3). [3] Like the standard deviation, the range of a random sample is a measure of scatter. R is the difference between the largest and smallest value in the sample, and although it is a less rigorous measure of variability than the standard deviation, its simplicity has led to its widespread use in control charts.

Control chart theory is based on the statistical central limit theorem. The central limit theorem states that the distribution of the means of random samples taken from a

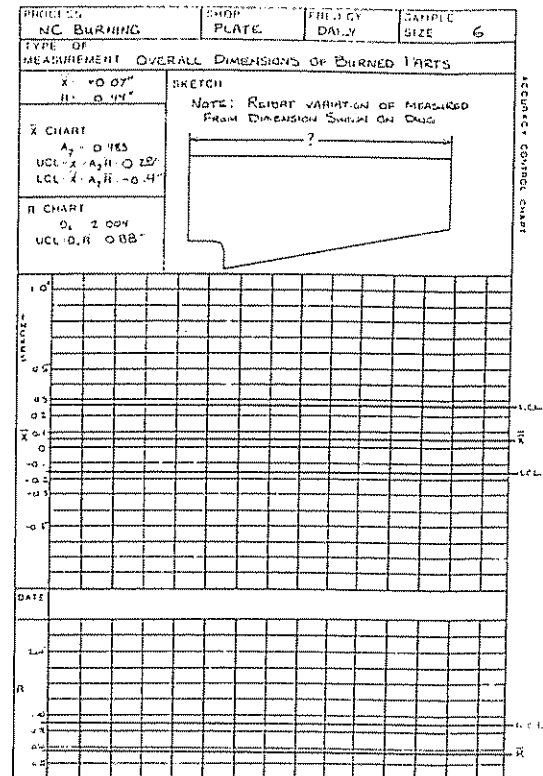


Fig 8-3 $\bar{x}$ and R control charts for variation of dimensions of N/C burned parts

normal distribution is another normal distribution with the same mean as the original distribution and a standard deviation equal to the standard deviation of the original distribution divided by the square root of the random sample size (see Figure 8-4). It also states that the distribution of means of random samples will follow a normal distribution, even if the samples are taken from a nonnormal population. This result can be used to detect changes in the original distribution, which would indicate the presence of special causes of variation.

The technique involves initially determining regular performance for a work process (i.e., its normal distribution) using a large data sample. This normal performance can be used to establish an expected range of variation for the process. Subsequent random samples of products from the work process can

then be monitored to detect changes in the performance of the process. Control charts establish limits on the variation of the mean and the range of these random samples. The limits are commonly set three standard deviations above and below the process mean and the average range. These limits are used because they provide 99.7 percent assurance that exceeding these limits is the result of a change in the normal distribution of the process and therefore the result of a special

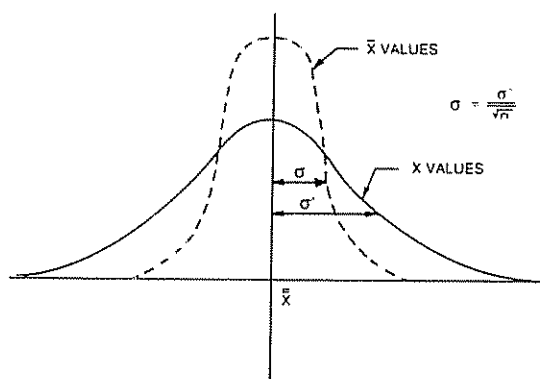


Fig 8-4. Normal distribution of random samples taken from a normal population.

cause. Data such as those shown in Figure 8-5 are used to determine individual entries to an $\bar{x}$ and an R chart.

The control charts provide information about a particular work process. Since some dimensional variation is a regular result of any work process, it is important to be able to distinguish between expected chance or random variations, and other variations. Thus the control charts are a tool to monitor work processes to assure that action need not be taken to maintain the usually achieved accuracy of the process.

Control charts are developed for a work process when the process is in a state of statistical control. Some understanding of the meaning of statistical control is important in using control charts. A state of statistical control is a state of randomness. When a process is in control and no special causes are present, variations on the $\bar{x}$ and R charts are due to common causes. Points plotted on the $\bar{x}$ and R charts will fall within the control limits. When points fall outside the control limits, they indicate the presence of a special cause of variation. The production worker

DESIGN NAME	TAGOS		HULL NO	1, 2	PLATE THK	5/16	NAME	JF3	DATE	1/30/83
PROCESS	NE BURNING		STAGE OF CONSTR	PARTS	MEASUREMENT DESCRIPTION	OVERALL DIMENSION				

PART NO	MEASURED		DIM. AS MEAS'D (A)	TARGET DIM. (T)	VARIATION (X-A-T)	NOTES
	FROM	TO				
1 TA:000004	a	b	192.56	192.69	-0.13	Turned first
2	c	d	192.56	192.69	-0.13	
3	a	c	59.87	59.84	+0.03	
4	b	d	59.87	59.84	+0.03	
5 TA:000047	a	d	47.63	47.84	-0.21	long L bhd 48" off C
6 TA:000046	FWD EDGE	LEFT EDGE	192.75	192.69	+0.06	long R bhd on C — Hull #2

$X_{min} = -0.21$	$\Sigma X = -0.35$
$X_{max} = +0.06$	

FORMULAS:

$\bar{X} = \frac{\Sigma X}{N}$

$R = X_{max} - X_{min}$

sample size ----- N = 6

ave variation ----- $\bar{X} = -0.06$

range ----- R = 0.27 in

Fig 8-5. Random sample data to be entered on an $\bar{x}$ and R control chart

can almost always detect and correct these causes. When in a state of statistical control, a work process has predictable and repeatable outputs. Thus, a state of statistical control is evidenced by random sample values of $\bar{x}$ and R falling within the control limits on control charts. The control limits and the sample size indicate the level of accuracy and the variation that can be expected.

In developing the $\bar{x}$ and R control charts, six values are required, three for each chart. These values are the centerline, the upper control limit, and the lower control limit (see Figure 8-3). For each work process, the $\bar{x}$ and R charts are based on an established and repeated sampling procedure. The sampling procedure includes a specified sample size, n . The control chart values are determined from the results of a series of random samples.

If k samples of size n are taken, the $\bar{x}$ chart values are:

$$\begin{aligned} CL &= \bar{\bar{x}} = \frac{\sum \bar{x}}{k} = \frac{\sum x_i}{n \cdot k} \\ UCL &= \bar{\bar{x}} + A_2 \bar{R} \\ LCL &= \bar{\bar{x}} - A_2 \bar{R} \end{aligned}$$

and the R chart values are:

$$\begin{aligned} CL &= \bar{R} = \frac{\sum R}{k} \\ UCL &= D_4 \bar{R} \\ LCL &= D_3 \bar{R} \end{aligned}$$

The constants, A_2 , D_3 , and D_4 are commonly available in listings of statistical constants and are a function of sample size, n .

1.1.2. Variation Merging. Ships are built by procuring or fabricating parts and then joining them to create subassemblies. In turn, these are combined through several manufacturing levels to produce increasingly larger subassemblies, blocks, and ultimately a complete ship. Production line techniques may be employed for the many different interim products required.

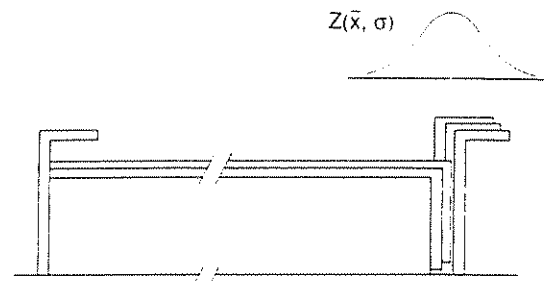


Fig 8-6 Merged variation of fitting flat bar between longitudinals

When each of the work processes is in statistical control, the normal distributions of variations for the work processes can be determined (mean and standard deviation). Based on these data, it is possible to predict statistically the merged variation from the total series of work processes that produce the ship. Consider the combination of two work processes, cutting flat bars (see Figure 8-1) and the spacing of longitudinals (see Figure 8-2). The mean and standard deviation of variation in fitting flat bars between longitudinals can be determined from the data of the individual work processes (see Figure 8-6). In addition to finding the normal distribution of variation of this latter assembly process, the work process which contributed most to the final or merged variation is identified.

Accuracy goals are expressed in terms of the normal distribution required for the final process. Then, by working backwards, necessary goals are similarly set for each of the work processes which would ensure desired accuracy for the final process. Since normal performances at each work station are known, alternative building strategies may be evaluated to determine if the reduction in rework can be obtained. If rework reductions by altering assembly sequences are not possible, steps to reduce the normal variations at critical work processes can be initiated. These may include replanning flow lanes,

improving work environments, retraining workers, or other similar approaches. This by-product of the accuracy control system is called process or method analysis. Process analysis involves a detailed review of a particular work process. The goal of this analysis is to reduce variability, i.e., to lower the mean variation and/or the standard deviation of the variations of the process. A similar approach can be applied to investigate special causes that are responsible for a process being out of statistical control.

Independent normal distributions, such as those representing performance of each work process, can be added to determine the expected normal performance at succeeding stages of construction. Additions of normal distributions apply both to work processes necessary to ensure needed accuracies of interim products and to interim products themselves to ensure required accuracy of a final product, such as a ship's hull. For the latter, the merged variation, Z , is expressed as:

$$Z = \Sigma P_i + \Sigma S_i + \Sigma A_i + \Sigma E_i$$

where:

ΣP_i = merged variations from all parts fabrication processes

ΣS_i = merged variations from all sub-assembly processes

ΣA_i = merged variations from all block assembly processes

ΣE_i = merged variations from all erection processes

This equation is referred to as the variation-merging equation for the completed hull.

The variation-merging equation is based on the theorem of addition of variance. Variance is simply the square of the standard deviation. For independent distributions, such as those representing the normal performance of work processes, the theorem of addition of variance states:

$$\sigma_F^2 = \sigma_1^2 + \sigma_2^2 + \sigma_3^2 + \dots = \Sigma \sigma_i^2$$

where σ_i is the standard deviation of earlier processes and σ_F is the standard deviation of a final process. [4]

1.2. Overview

A production line consists of sequentially arranged work processes; it is a preplanned entity. Efficiency is dependent upon uniform work flow and coordination with other production lines. Optimum accuracy is crucial to avoid disruptive rework. Even nominal rework can break down the economic advantages of a production line. Thus, when thinking about how a ship is to be assembled, planners must address their shipyard's accuracy capabilities. Accuracy control planners need good systems for collecting and evaluating accuracy data.

In the absence of such measures, the following typical questions are disregarded:

- What dimensions are vitally important to achieve required accuracy?
- How is the required degree of accuracy going to be achieved?
- In what work processes should vital dimensions be controlled?
- What are the tolerances that should be imposed at each work process?

Without tolerances specified for each process, there is no way to control the accumulation of variations at a final process. Tolerances in shipbuilding can be classified in two groups:

- end product tolerances, where some are fixed, as by classification societies, and others can be negotiated, as those requested by owners
- interim product tolerances, which are applied by a shipyard to ensure compliance with end product tolerances and simultaneously to maximize pro-

ductivity (tolerances for productivity reasons are often more demanding than those imposed by classification societies and owners)

As a shipowner's guide to what tolerances can be achieved at reasonable costs, data based on actual results can be collected. These data:

- apply to many details, parts, and subassemblies
- provide standard ranges of actual dimensions achieved, which by definition reflect 95 percent probability for normal shipyard practice
- provide tolerance limits, which are criteria for rework
- are periodically revised to incorporate the effect of continuing improvements in shipbuilding technology

Shipowners have to pay more if they specify closer tolerances than those normally achieved as described above.

Standard ranges are indicated with the same plus and minus notations used to fix tolerances. However, they are not really tolerances. Instead, they reflect usual capabilities with 95 percent probability of the processes used by the shipyard from which data were collected. Tolerance limits should encompass their associated standard range, as shown in Figure 8-7. Where they do not, rework can be regularly expected.

An important aspect of accuracy control (A/C) is the difficulty commonly encountered in joining blocks during hull erection. Erection joint gaps that are not within tolerance limits must be reworked by gas cutting and/or back strip welding (see Figure 8-8). Applying A/C to all earlier work processes is more productive than having to deal with merged variation in relatively inaccessible and hazardous locations in a building dock or on the ways.

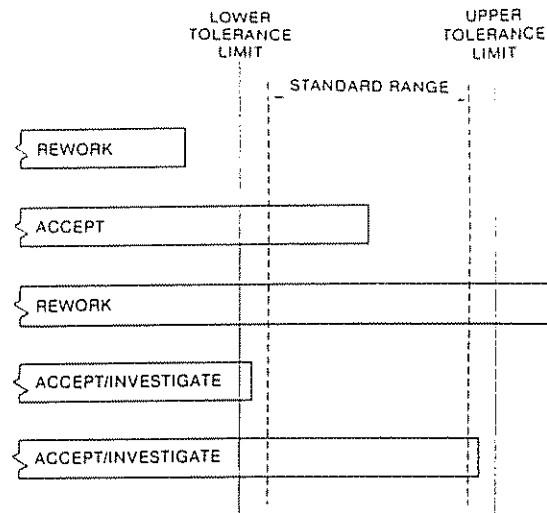


Fig. 8-7 Relationship of standard ranges and tolerance limits

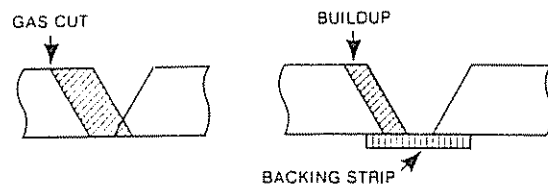


Fig. 8-8. Erection joint gap rework types

Margins to be trimmed at an erection site are commitments to rework, so their use should be minimized. Statistical methods could be used to anticipate normal dimensional variations and to provide compensation, such as specific allowances for excess. Thus excess is applied to dimensions to account for shrinkage that is predicted by statistical analysis, while margins are applied where shrinkage cannot be predicted. Most of the edges of parts, subassemblies, and blocks are finish-cut accordingly.

A/C starts with statistical analysis of variations generated at each of the prerequisite work processes for hull erection, including work processes during block assembly, subassembly, parts fabrication, lofting, and design. Measurements recorded for any work

process, when plotted by frequency of occurrence versus magnitude, usually follow the normal (Gaussian) distribution, if the work process is repetitively applied without change. The use of repetitive work processes is a key to group technology shipbuilding and is also essential for valid statistical analysis.

Obtaining a mean and standard deviation for each process makes it possible to:

- express the standard deviation of variations at erection as a combination of the deviations of variations from preceding work processes
- establish an order of priority for "tightening up" preceding work in order to reduce the accumulation of variations for the final work process
- establish accuracy standards
- revise written work and A/C procedures
- direct improvements in design details to minimize requirements for high degrees of accuracy

Generally, work processes which require statistical analysis are:

- parts fabrication
 - marking
 - cutting
 - bending
- subassembly
 - fitting
 - welding
 - fairing
- block assembly
 - plate joining and fitting
 - automatic welding
 - marking
 - cutting
 - assembly and fitting

- welding
- fitting of reverse side members and welding
- erection
 - positioning
 - welding

As shown in Figure 8-9, any A/C activity can be classified into one of three basic management functions that are inherent in any industrial enterprise. These are planning, executing (field work), and evaluating (analyses and feedback). Thus, A/C responsibilities can readily and effectively be incorporated into any existing organization provided:

- one manager has responsibilities for all, not just A/C, planning, executing, and evaluating of operations
- planning includes design and material definition
- within organizations such as a hull structural design section, production planning group, or subassembly section, people with pertinent engineering qualifications are assigned specific and substantial A/C responsibilities

Effective A/C is critically dependent on unified operations, organized information, and qualified incumbents. A special A/C organization is not a prerequisite. In fact, involving all aspects of the shipbuilding organization with A/C is preferred. The specific people throughout a shipyard who are assigned A/C responsibilities must at least function as a de facto A/C group. The person who maintains the principal A/C overview for an operations manager is a key individual.

2. Planning

Accuracy control planning is essential to the proper functioning of the system. The work is closely associated with regular design, engi-

neering, and planning. Figure 8-10 outlines the accuracy control planning process and shows the natural relationship to design,

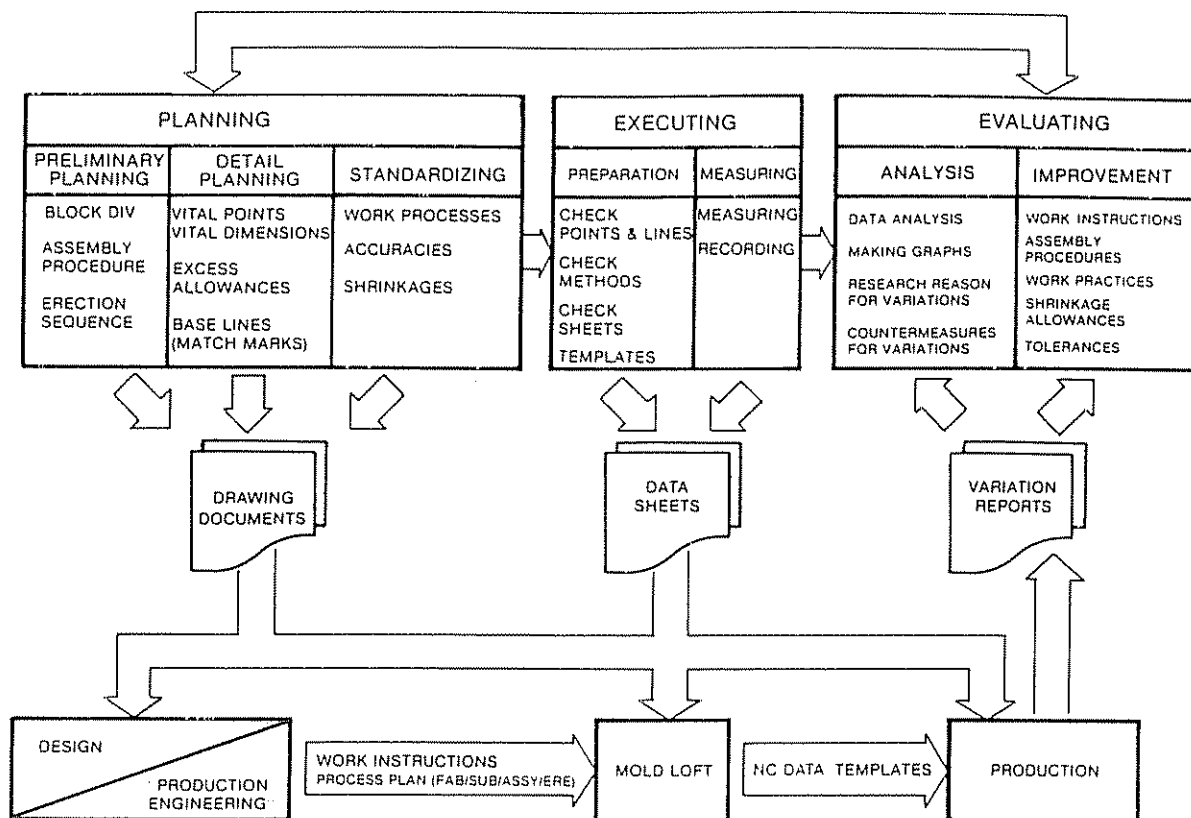


Fig 8-9 Accuracy control cycle

engineering, and planning. Since variations will occur at each stage of production (see Figure 8-11), one aspect of accuracy control planning is to indicate when (at what stage of construction) action must be taken to minimize rework at erection. Figure 8-12 shows when A/C activities are applied.

Basically, what is shown is the role of A/C planning to:

- pinpoint what vital points and dimensions are critical to the dimensional and geometrical accuracy of blocks
- designate critical checkpoints and reference lines in blocks and in the subassemblies and parts from which blocks are assembled
- specify locations for and amounts of excess allowances

- decide where and how much margin is to be used and the specific stages at which margins should be cut neat
- determine work processes during which check measurements will be made
- fix the numbers of interim products that should be measured based upon random sampling
- incorporate tolerance limits, excess allowances, and margins in work instructions

A/C planning is best performed together with other planning elements, provided it receives at least the same emphasis. For effectiveness, specific A/C responsibilities should be clearly defined and specifically assigned to individuals. As previously shown in Figure 8-9, A/C planning can be divided as other major

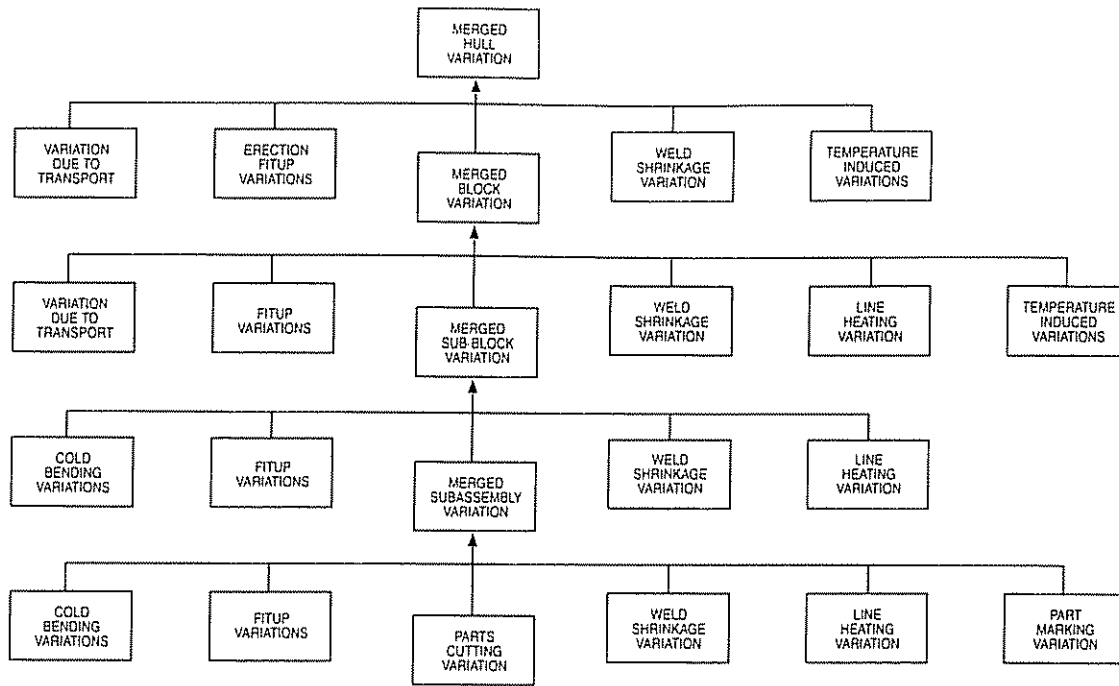


Fig 8-11 Sources of variation by stage of construction

- shape blocks that are spacious and open, to facilitate zone outfitting

To carry out such studies systematically, planners must have access to drawings, such as a general arrangement, midship section and lines plan, and proposed schemes for block divisions and shell straking. The planners, who are assigned at the hull construction department level and to the parts fabrication shop, subassembly section, block assembly section, and erection section, are furnished these drawings by the design department. As a routine matter, the same information is available to the planners who have been assigned A/C responsibilities. They use the variation-merging equations, based upon statistically obtained assessments of normal performance at workstations, and propose optimum design details, assembly and erection sequences, tolerances, etc., accordingly. The final scheme is fed back to designers, who

then develop key plans, such as a shell expansion, a block plan, and ultimately work instructions, all of which contain A/C-derived requirements.

2.2 Detail Planning

Accuracy control considerations in detail planning are really process analyses from an A/C viewpoint. Through such analyses, problems which can be solved by regulating certain dimensions are revealed in advance. In other words, to obtain required accuracy for a final process, it is necessary to identify the specific preceding processes that are significantly contributing to a final or merged variation. Thus, A/C analyses identify on a quantitative basis both the work processes and the design details which should be improved.

Of course, such determinations are not made solely from an A/C viewpoint. Accuracy control techniques are analytical management tools that contribute to process analyses. They are the means for a shipyard as an

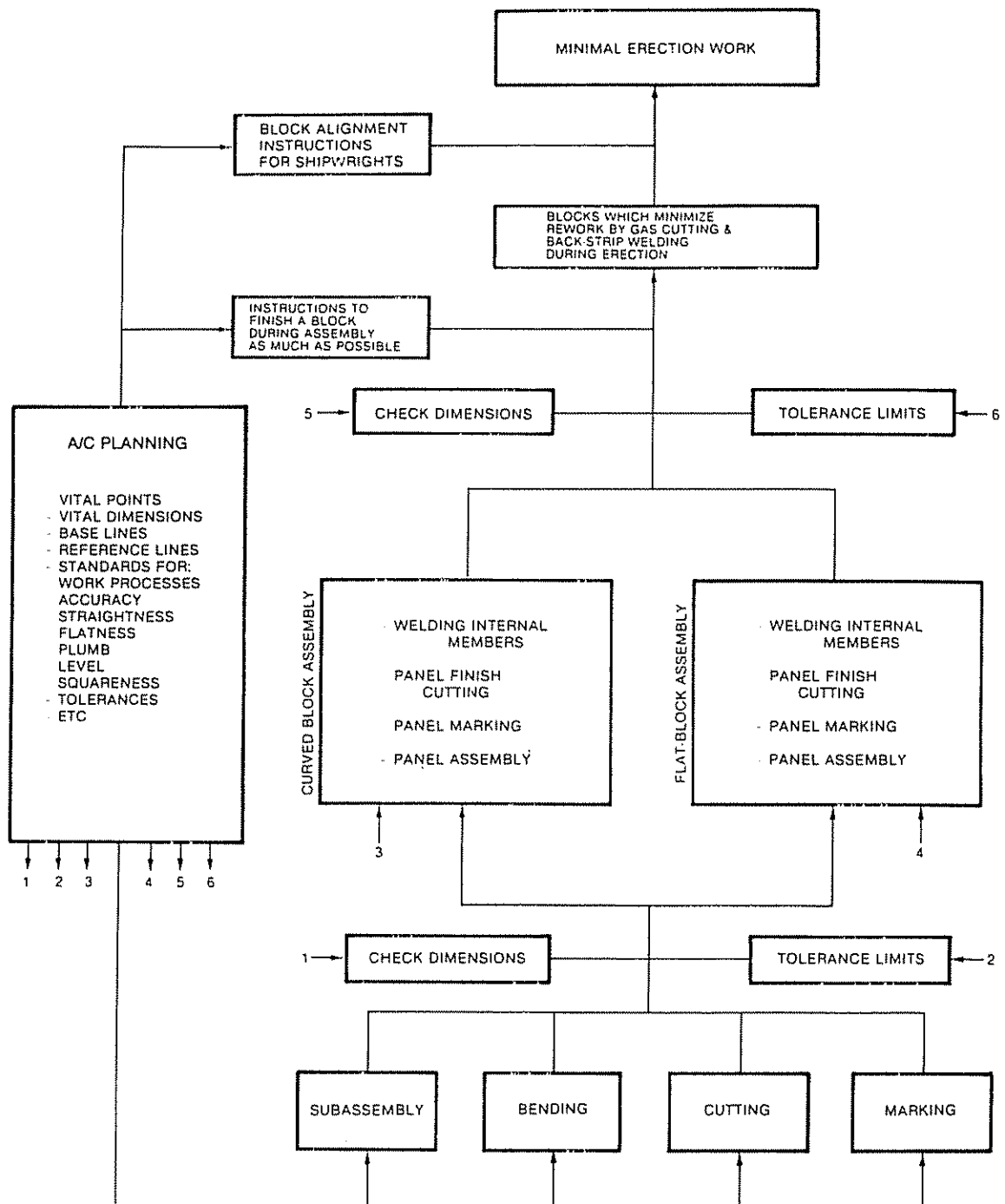


Fig 8-12 Stages at which accuracy control measurements are taken

entity to capture and quantitatively derive benefits from its accuracy experiences. Accuracy control methods in detail planning are significant because they inherently address the entire hull construction process for the purpose of reducing erection work.

Planning proceeds by first assessing the accuracy characteristics for an end product as specified by a regulatory society and shipowner. Thinking of reverse process flow, A/C planners identify vital points and dimensions that must be maintained during erection, block assembly, and so on (see Figure 8-13). In consideration of such vital aspects, A/C planners ensure that, via work instructions and other means, loftsmen and people having A/C field responsibilities are provided with necessary information, such as checkpoints

and reference lines that must be included in numerically controlled (N/C) data, templates, and field check sheets. Engineers who perform A/C planning for construction of a ship recognize that most accuracy variations in work processes are normal, and their impact on an end product can be predicted through statistical methods.

Simultaneously with the designation of required work procedures for a specific interim product, tolerances and amounts of excess are determined by taking into account the merging of variation. Variations generated by each work process follow a normal distribution, $N(\bar{x}_i, \sigma_i)$, and accumulate as another normal distribution, $Z(\bar{z}_F, \sigma_F)$, at the last stage. In order to reduce the merged mean variation, $\bar{z}_F$, it is necessary to reduce

Type of Vital Check Points or Baselines	Examples	Why These Measurements Are Important
Characteristic hull dimensions	1 straightness and level of hull baseline 2 length, draft, breadth of various points 3 hull volume—offsets at chine or bilges 4 tonnage/tankage measurements	1 satisfy regulatory bodies 2 establish capacity/tonnage 3 quality assurance to customer 4 feedback to yard—A/C analysis 5 feedback to standards organizations—modify standards 6 affect erection productivity
Dimensions related to operating requirements	1 relative position of stern tube, shaft bearings, engine foundation and rudderpost 2 location/alignment of special components—roll-on/roll-off ramps, gun mounts, etc. 3 special customer requirements	1 affect performance, operation of vessel 2 feedback to yard—A/C analysis 3 feedback to standards agency 4 affect productivity of component installation 5 satisfy special customer requirements
Major structural intersections at butt joints	1 shell plate offsets at butt 2 chine offsets 3 locations of major bulkheads 4 large structural foundations—location, flatness	1 affect strength, rework requirements, deformation during fabrication 2 feedback to yard—A/C analysis 3 feedback to standards agency 4 affect fabrication productivity
Outfit component intersections at butt joints	1 pipe ends which mate to another component on adjoining unit 2 machinery components mating to component on another unit 3 pipe penetration locations	1 affect proper operation of machinery 2 affect productivity of zone outfitting 3 feedback to yard—A/C analysis 4 feedback to standards agency
Process related measurements	1 fit-up gaps 2 welding shrinkage 3 welding distortion 4 bending accuracy 5 line heating 6 cutting, marking accuracy 7 curvature of components fabricated on pin jig	1 assist determination of process accuracy 2 affect productivity of subsequent processes 3 feedback to yard process evaluation 4 feedback to standards agency
Measurements to facilitate fabrication	1 platen level 2 jig alignment/accuracy 3 building dock baseline alignment 4 baselines on parts, blocks to facilitate measurements, alignment, assembly, outfit, painting and erection	1 assist fabrication 2 affect productivity 3 feedback to yard—A/C analysis of alternative methods/processes

Fig 8-13 Vital points and dimensions

the standard deviation, σ_i , and control the mean value, $\bar{x}_i$, of each process, considering their effects on current production methods.

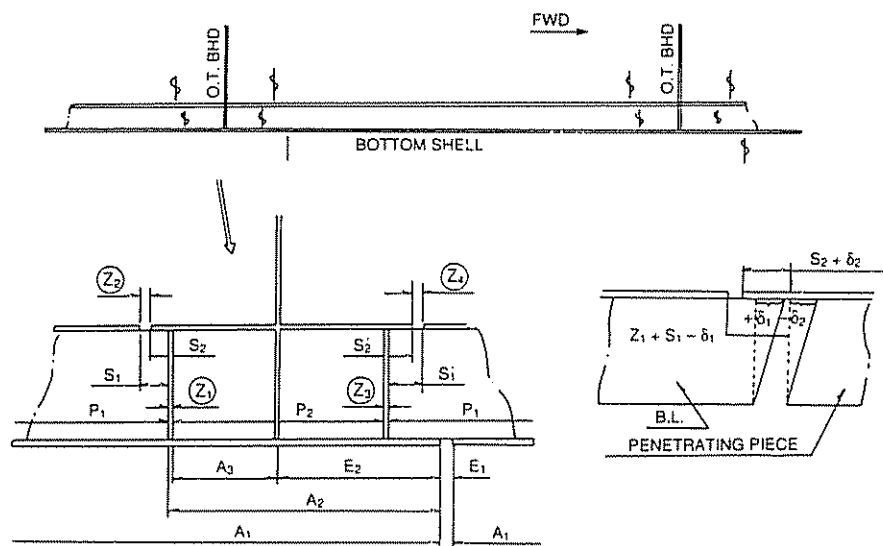
An example of how A/C planners can use variation-merging equations to predict merged variation in a bottom butt to be joined during hull erection is shown in Figure 8-14. Using these results, accuracy control planners perform process analysis to improve design or to alter work sequences to improve accuracy and productivity.

A/C planners also apply these techniques to predict merged variation within every manufacturing level. For example, for block assembly they use the normal distributions for each work process, such as panel

assembly, panel marking, panel finish cutting, and internal member welding to predict the normal distribution for blocks being planned. The same technique is employed for subassembly and for parts fabrication. This enables A/C planners to advise designers of specific A/C matters that are to be included in work instructions.

2.3. Standardization

Standardization is an important feature of group technology shipbuilding, as was discussed in Chapters VI and VII. Standards related to accuracy control can be discussed in terms of work standards and accuracy standards.



Assembly Procedure:

1. Fit the flange on the web shifted by S_1 (fwd end of longitudinal).
2. Fit the flange on the web shifted by S_2 (aft end of penetrating piece).
3. After the plates are welded together to create the bottom panel, incorporate a 3mm excess allowance and finish cut the panel's forward edge.
4. Fit the longitudinals to the bottom panel shifted by A_2 where $A_2 = \text{the designed dimension} + 2\text{mm}$.
5. Fit the penetrating piece to the transverse bulkhead at the distance A_3 .

Variation merging equations for the joint gaps during hull erection:

$$Z_1 = A_2 - (A_3 + E_2)$$

$$Z_2 = Z_1 + [(S_1 - \delta_1) - (S_2 + \delta_2)]$$

$$Z_3 = [E_2 - (P_2 - A_3)] - [(P_1 + A_2) - (A_1 + E_1)]$$

$$Z_4 = Z_3 + [(S_1' - \delta_1') - (S_2' + \delta_2')]$$

- A negative value for Z predicts overlaps, i.e., negative gap
- The value for every A , E , etc., is dependent upon a similar lower-tier equation which accumulates variations for marking, cutting, etc., as measured from a reference line

Fig 8-14(a) Variation merging equation example (continued in Fig. 8-14(b)).

ESTIMATED MERGED VARIATION (Z)					
Dimension	Sample size n	Mean value $\bar{x}$	Variance σ^2	Remarks	
P ₁	126	+0.4	0.91	Length of bottom longitudinal after web is welded to flange	
P ₂	50	+0.5	0.79	Length of penetrating piece after web is welded to flange	
δ_1, δ_2	156	0	0.51	Perpendicularity of bottom longitudinal and penetrating piece ends	
δ_1, δ_2					
S ₁	140	+1.1	0.61	Fitting position of bottom longitudinal flange	
S ₁	140	+0.5	1.61	Shift between web and flange at the after end of bottom longitudinal	
S ₂	50	-0.4	0.81	Fitting position of flange of penetrating piece	
S ₂	50	+0.6	1.82	Shift between web and flange at the forward end of penetrating piece	
A ₁	36	+2.9	1.38	Length of bottom panel after finish cut	
A ₂	83	+1.6	1.64	Fitting position of bottom longitudinal	
A ₃	70	-0.8	2.02	Fitting position of penetrating piece	
E ₁	42	-0.4	2.43	Accuracy of gap between bottom panels measured between reference lines after welding	
E ₂	44	+1.9	4.60	Erected position of Transverse Bulkhead; Distance from butt of bottom panel	
Estimated Gap					
Z ₁	_____	+0.5	8.26	_____	7%
Z ₂	_____	+2.0	10.70	_____	17%
Z ₃	_____	+1.0	13.79	_____	14%
Z ₄	_____	+1.0	18.22	_____	17%

* Estimated occurrence of gaps which are 5 or more mm wide; back-strip welding is required

ACTUAL MERGED VARIATIONS					
Actual Gap	Sample size n	Mean value $\bar{x}$	Variance σ^2	Actual occurrence of back-strip welding	
Z ₁	85	+0.8	7.61	4%	
Z ₂	82	+2.3	9.71	12%	
Z ₃	78	+1.1	10.02	6%	
Z ₄	72	+2.2	13.75	13%	

Fig. 8-14(b)

2.3.1. *Work Standards.* Any work process can be performed with varying degrees of accuracy. When it is controlled so that it is always performed the same way, variations will be normally distributed and can be analyzed statistically. Without such controlled work processes, statistical analysis is not valid. Thus a crucial part of A/C is to ensure that accuracy variations remain random and are not the result of arbitrarily introduced bias. Standardization of work processes and monitoring to ensure compliance are fundamental

concerns of A/C people. A/C authorization of a proposed change in any work process permits quantitative analysis of its impact on the entire shipbuilding process. This rigid control does not mean that changes are not made. Instead, adjustments to work processes are more frequent due to the continuous process analyses and feedback that are inherent features of A/C.

Related standards should be written and adhered to for such matters as planned steel flow, worker organization, worker training,

and supervision. If any are changed without regard for A/C analyses and approvals, biases that invalidate previous A/C or process performance data are introduced.

Among the work standards required are those for:

- excess
- shrinkage allowance
- baselines and match marks
- checking procedures
- parts fabrication and assembly schemes
- A/C information in work instructions

At the startup of A/C planning, the following questions are asked to determine standards for excess:

- Why are margins needed?
- Where are margins required?
- How much margin is necessary?
- During what work process will margins be finish cut?

Usually, a margin scheme for main strakes, such as shell plates, is created by production planners. Margins shown are for ordering materials and/or fabricating parts. However, the amounts of margin are not prescribed by written standards that are backed up by records of measurement data. In this respect, margins differ from excess allowances. Margins are used as a buffer to compensate for accuracy variations in all hull construction processes, including design. Therefore, the true causes of accuracy variations and ways to improve fabrication methods are difficult to detect. Where statistical analysis is not applied, the large amounts of margin used are based on "rough check" data which characterize feedback from production. This cycle masks actual causes and reduces opportunities for improvements.

A/C scrutiny shrinks margins until most of them become just the excess allowances needed to compensate for variations. Excess

is characterized by finish cutting, based on a high probability that no rework will be required. To further eliminate rework, A/C continues to impose the same questions when this transition is achieved:

- Why is excess needed?
- Where is excess needed?
- How much excess is necessary?
- If needed, during what stage should rework take place?

This incessant questioning is motivation for continuous improvements in work methods.

The amount of shrinkage caused by welding will be different, depending upon materials, methods, and sequences. Thus, standards for shrinkage allowances must be based upon recorded data for each set of circumstances.

Baselines and match marks are both necessary and important to facilitate proper data collection and to aid production, especially fitting. Standards are required to assure that their locations and lengths are sufficient to reflect production requirements.

A written checking procedure assures specified accuracy at each work process. Written checking procedures (standards) are required to ensure that measurements are recorded for analysis.

The sequences for subassembly and block assembly are usually indicated by a numbering system, useful for computer processing, which is hierarchical in order to match ascending manufacturing levels. This system is good enough to indicate a simple sequence such as parts fabrication, subassembly, block assembly, and erection. Standards for parts fabrication and assembly schemes that address vital points and dimensions are needed to achieve specified accuracy during each work process.

Usual hull construction drawings show structural details and sometimes include instructions for edge preparations. Specific excess allowances are generally not included

Little other guidance is provided by designers to indicate fabrication methods and vital points and dimensions needed to achieve a specified degree of accuracy. Working drawings, provided to workers, are the only widely distributed documents which can display total instructions for how to construct a ship's hull. When design is recognized as an aspect of planning, working drawings will develop more as work instructions which facilitate employment of less skilled workers, adherence to work standards, A/C analyses, and continuous improvement in production methods.

2.3.2. Accuracy Standards. To control the accumulation of variations or merged variation at a final stage, accuracy standards are established for preceding work processes. Figure 8-15 shows the relationship among accuracy standards by stage of construction. Data obtained during construction of other ships are used to derive accuracy standards for a contemplated ship. However, these are reviewed by analyzing data recorded as production begins and progresses. Adjustments are made if assumed accuracy standards are unrealistic.

The concept of a standard range with a tolerance limit, as shown in Figure 8-7, is

applied to every work process. The more demanding standard range is used as the accuracy standard for each particular work process in order to ensure control of the merged variation at erection. By definition, standard range is associated with high probability ($\bar{x} \pm 2\sigma$ or 95 percent).

Of the few remaining variations, those outside the standard range which do not require rework during the next work stage, nor spoil end product accuracy, are acceptable and are regarded as being within a tolerance limit. This is a tolerance limit because it applies to fewer cases and includes some added allowance for acceptance. However, such limits must be achievable with normal production capabilities and must not impair structural integrity of the end product.

This approach recognizes basic realities in any industrial enterprise. While more demanding accuracy standards are applied to normal operations, some allowance is made for the effect on accuracy of on-the-job trainees, newly developed machines, etc. The concept of a standard range with a tolerance limit encourages managers to react to trends away from normally achieved accuracy before rework is required.

3. Executing

Accuracy control execution is concerned with two tasks:

- define when, what, and how to measure
- take measurements and record data

Before looking into the various aspects of the execution phase, it is useful to review the purpose of this effort. The objectives of an accuracy control program are to determine that work processes are in a state of statistical control, to maintain that state of control, and to provide information to management to facilitate process analysis and improvement. The first two are important both in the short

and long terms. Production workers can monitor the work processes with the aid of control charts and make adjustments when necessary to maintain the desired state of control. This has obvious short-term benefits in decreasing product variability and hence improving productivity. Maintaining processes in control has the additional purpose of ensuring the validity of a statistical analysis of those processes. This process analysis to continuously improve productivity is the third objective. It is this analysis that provides the principal motivation and benefit of an accuracy control program.

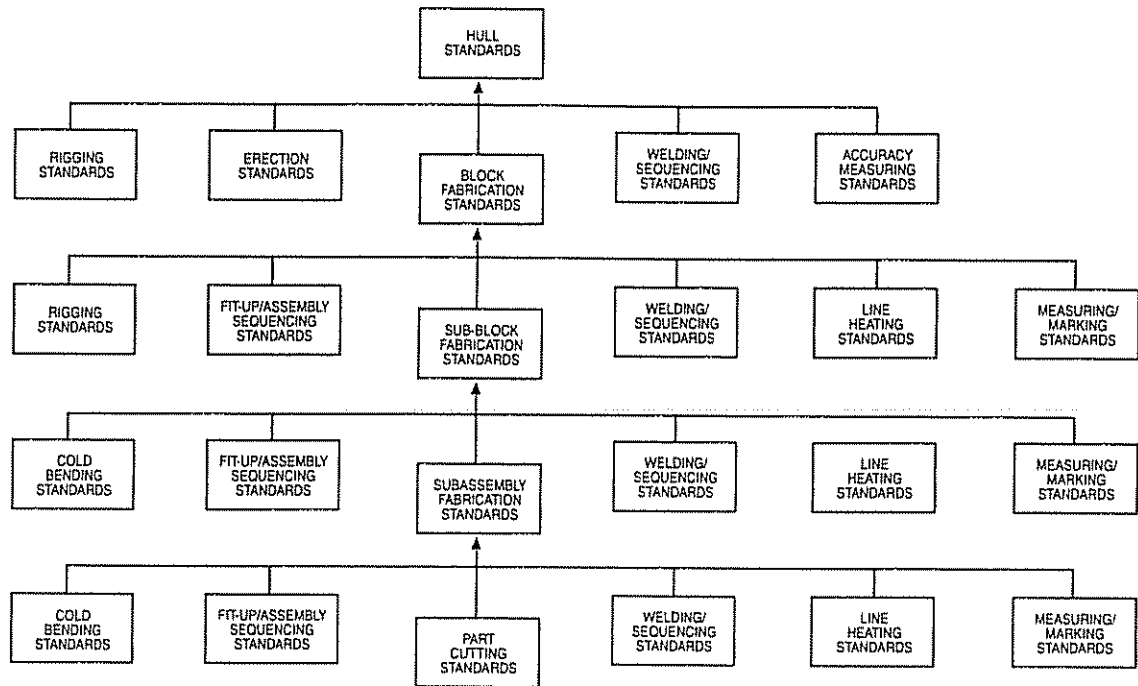


Fig. 8-15. Relationships among accuracy standards and stages of construction

3.1 Self-Check

Accuracy control includes a self-check system that workers and their immediate leaders execute. Self-checks are crucial. Workers (or work groups) have not completed a job until they have checked their work to assure compliance with written accuracy instructions. Thus, self-checks should be regarded as production work just as much as any other work task. Subsequently, work leaders, one for every work group (approximately eight workers), check the same work and record the pertinent final data. Very important checkpoints and lines, often called control items, are again checked and recorded by the next higher level of supervision. If such data are unreliable or not available, an A/C system is ineffective.

3.2 When and What to Check

Start and finish date schedules are usually posted at each control station for parts fab-

rication, subassembly, and block assembly. Summary sheets for future work loads are also posted. Self-checks, subsequent checks, and recordings are regarded as work processes that must adhere to these schedules. Posted records in each division of production show the day-to-day status.

Normally, the master schedule for block erection, weekly progress sheets, and a schedule for erection checks based on the master schedule are posted in an erection office. The status of block erection is maintained on a day-to-day basis.

Accuracy checks are performed daily in accordance with schedules that are revised weekly, if necessary. For each work stage, items are checked for conformance with accuracy standards. These are:

- for template preparation: overall dimensions, including excess allowances and marks required for parts fabrication, assembly, and checking work

- for parts fabrication: overall dimensions of cut plates or shapes, edge preparations, deformation, and the curvature of bent parts
- for subassembly and block assembly: the positioning of parts or subassemblies, their fit, gaps for welding, distortion, and overall dimensions
- for erection: fit-up, gaps for welding, and maintenance of hull alignment

3.3 Information for Check Sheets

Members of an A/C group in a hull construction department prepare check sheets in accordance with work instructions issued by designers and based on information provided by A/C planners. The check sheets designate checkpoints and lines, checking methods, personnel responsible for measuring, and required frequency for measuring. A typical example of a check sheet is shown in Figure 8-16.

Preparing check sheets for curved blocks is usually difficult, because the dimensions included in normal working drawings, while sufficient for assembly work, are not suitable for checking purposes. The simplest example is the two diagonals required for verifying the rectangularity of a panel. The A/C group advises loftsmen to calculate numerous other special dimensions that facilitate accuracy checks.

Actual measurements are mainly performed as specified by the check sheets. However, check sheets cannot practically provide for all dimensions for all hull parts and assemblies. There has to be some dependence on supplementary routine checking of other dimensions by workers. This helps ensure that the dimensions required by check sheets will satisfy accuracy standards.

3.3.1 Parts Fabrication. To achieve specified accuracy during assembly work, each of many parts must be fabricated within speci-

fied accuracy standards. Because measuring every dimension of every part is impractical, random sampling is employed to monitor accuracy tendencies. Special or large structural parts, such as girder or transverse web assemblies, are exceptions. Each should be measured in accordance with check sheet instructions, with particular attention to deformation. When cutting machines, such as N/C, are employed, their maintenance is a significant factor in the uniform working circumstances which are the bases for a valid random sampling. Maintenance checks on cutting machines should be frequent and regular.

The accuracy of bent parts is critical for achieving the accuracies specified for assemblies. Inaccurately bent parts are frequently forced to fit and are the sources of internal stresses which cause deformation when welding. Thus, all curved shell parts should be checked, using sightline templates and other information provided by loftsmen to establish for each plate as required:

- degrees of inclination for setting the templates
- matches of the plate edges with seam marks on the templates
- clearances between the template edges and plate surfaces
- transverse and longitudinal curvatures
- twisting
- straightness of the sightline (see Figure 8-17)

Analogous techniques and checks apply to other parts, such as twisted longitudinals.

3.3.2 Subassembly. Typically, the fit of stiffeners, brackets, and faceplates, such as on a web plate, and how to prevent and/or deal with deformation and shrinkage caused by welding, are important for A/C of subassemblies. Therefore, measuring activity during subassembly should concentrate on checking fitting dimensions, checking for deformation

DESIGN NO. TACOS BLOCK 6 SUB BLOCK 701E TA 1000123 AS CUT/WELDED

Part Description MAIN DECK Page 1 of 1 Drawn Jrg Date 4/30/84

119 87

ACCURACY CONTROL CHECK SHEET

HULL NO. 1 DATE Checked Temp Shop where checked assembly plate Checking Personnel Jrg and RLs

MEASURED	FROM	TO	DIMENSION AS MEASURED	ITEM	NOTES
1	b	d	28' 10 3/8"	Half - Brackets	
2	d		20' 4 1/2"		
3	f		19' 11 5/8"		
4	a		20' 10 3/8"		
5	c		20' 4 1/2"	L CHECKS	
6	e		19' 11 3/4"		
7	b	g	38' 7 5/8"		
8	a	g	38' 7 7/8"	Lengths	
9	a	e	15' 1"		
10	b	d	15' 1 1/8"		
11	a	e	27' 1 1/8"		
12	b	f	27' 1 1/8"		
13	h	g	33' 2 1/4"		
14					
15					
16					
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23					72
24					

Fig 8-16 Accuracy control check sheet

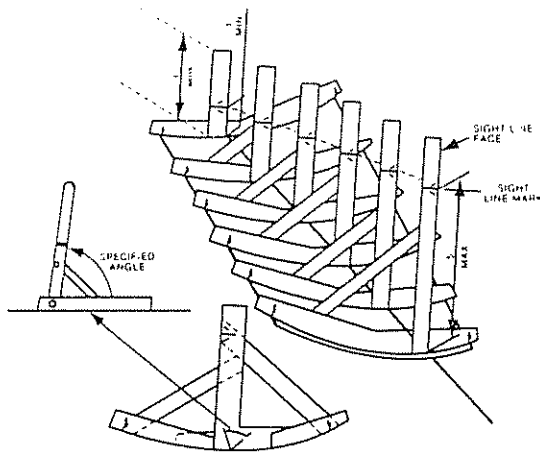


Fig 8-17 Sight line templates for checking curved plate accuracy

and shrinkage by using a reference line on a web plate and/or a straight edge of the web plate, and measuring other dimensions as indicated on a check sheet.

3 3 3 Block Assembly. Achieving specified accuracy in an assembled block is most important, because the block assembly process offers the last opportunity to deal with variations that otherwise have to be considered during erection. Regardless of their shapes, blocks are categorized by the panel (flat or curved) on which they are assembled. Typically, the former are assembled on flat platens and the latter on pin jigs. Measurement methods for the two types are necessarily different. Flat block check sheets should include the following requirements:

- measurements of width, length, and diagonals to be made just after the base panel is assembled
- twisting
- locations of subassemblies and internal parts fitted after the base panel is completed
- special measurements to check unique aspects of flat blocks which incorporate some curved shell (see Figure 8-18)

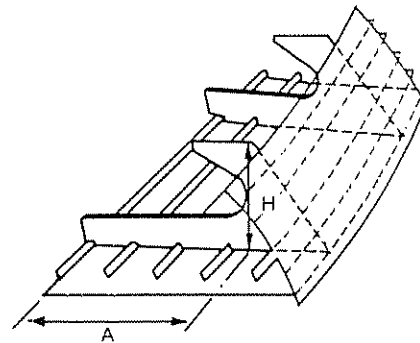


Fig 8-18. Vital dimensions on a flat block which incorporates some curved shell

Curved block check sheets should include the following requirements:

- measurements to check guides for precisely locating curved plates for a base panel on a pin jig
- measurements of width, length, diagonals, and chord lengths to be made just after a base panel is assembled
- use of marked steel tapes prepared by loftsmen for checking assembly finish marking, i.e., the locations of subassemblies and internal parts on a curved panel
- means to verify the fitting angle of internal structure
- instructions on how to detect and correct deformation caused by welding
- meticulous checking of required dimensions between panel edges and the edges of internal structure, particularly near erection joints

3 3 4 Hull Erection. During the erection stage, the object is to at least achieve end product accuracy standards specified by regulatory societies and owners for hull depth, breadth,

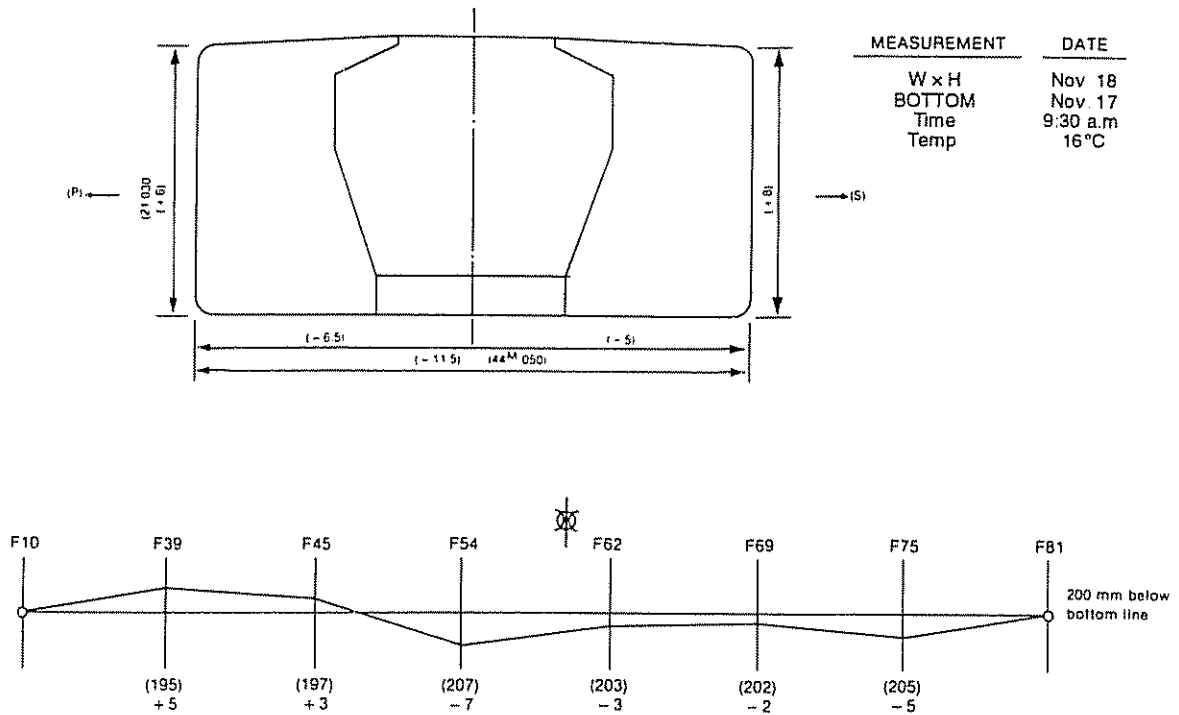


Fig. 8-19. Accuracy control measurements during erection.

length, and straightness. A/C personnel monitor vital points and dimensions by measuring and recording periodically, based on

check sheet instructions during the entire period between keel laying and launch (see Figure 8-19).

4. Evaluating

Systematized A/C analysis and feedback ensures that experiences and lessons learned are acquired by the organization and translated into improved productivity. As work progresses, all results from check sheets and reported accuracy problems are analyzed before they are sent to cognizant organizational divisions. The evaluations include analysis and recommendations which, as shown in Figure 8-20, are performed on either a regular or an urgent basis

4.1. Regular Analysis

If an analysis discloses an apparent area for improvement, an A/C engineer pursues one or more typical options as follows:

- more detailed investigation of the data
- investigation of instruments used for measuring
- verification of alignment of facilities such as platens for flat block assembly and cribbing for erection
- review of work methods
- study of specified amounts of excess

Workers perform self-checks daily to ensure compliance with accuracy standards. These are again checked and recorded by their work leaders. Properly collected data, even if all measurements are within accuracy standards, are used to identify the characteristics

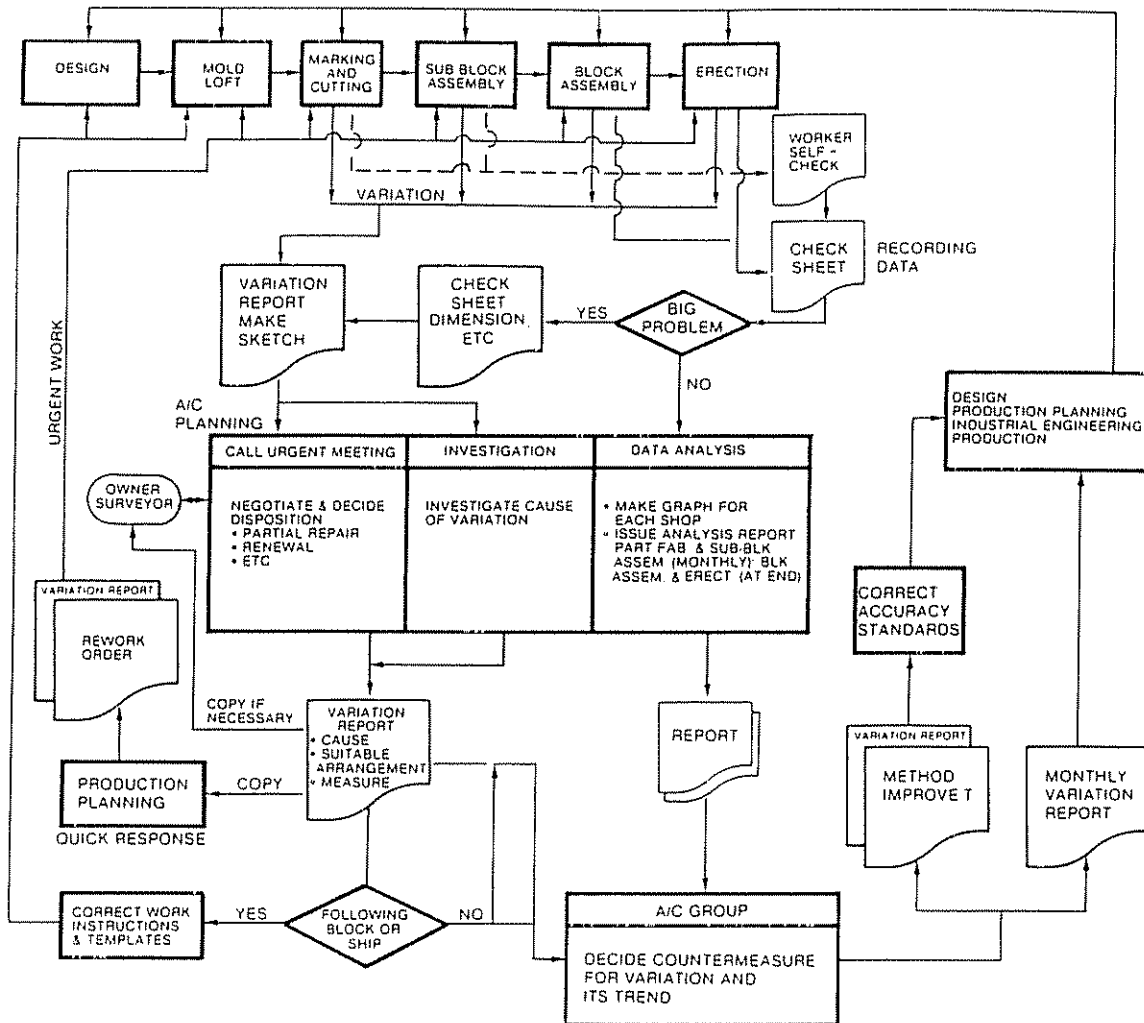


Fig. 8-20 Accuracy control information flows.

and tendencies of variations. Such knowledge leads to further improvement in production processes.

Feedback of analyzed A/C data is vital because it encourages planners to review items such as:

- whether schemes for amounts of excess, vital points, and dimensions, etc., were satisfactory
- whether block divisions and shell straking were optimum
- whether work process standards were suitable

- whether sufficient work instructions were provided

4.1.1. *Analysis of Mean Value.* For most work processes, the mean value for variations is planned to be zero. If the actual mean value differs from zero, it should be changed to match results of the work process, or the work process should be changed to yield the planned mean value (zero). This mean value is the grand mean that is used as the center-line on the $\bar{x}$ control chart, and not the mean of one or a few random samples. The following examples apply:

- *Example 1:* Consider a particular dimension for panels, such as for a longitudinal bulkhead under a tank top, which were cut with some allowance for shrinkage. After welding during sub-assembly work, the grand mean value of the dimension was determined to be negative; i.e., some shortage exists compared to the planned zero value. *Analysis:* Check kerf compensation; if sufficient, the allowance for shrinkage was too small.

Remedy: Add the absolute mean value to the previously planned allowance for shrinkage.

- *Example 2:* Near the end of flat block assembly, checking discloses that plates in tank top panels are deformed at their centers with a mean value of $\frac{1}{2}$ inch.

Analysis: Check the level of the platen on which the flat blocks were assembled.

Remedy: If the platen is true, improve the assembly work processes; e.g., apply pre-tensioning or change weld sequences.

4.1.2. *Analysis of Standard Deviation.* Standard deviation is significant for a number of reasons. It provides the linkage between the accuracies of earlier work processes and the accuracy of a final process, through the theorem of addition of variance. Without this relationship, analytical A/C does not exist. During analysis, A/C engineers should watch for a change or shift in the standard deviation for each work process. Such behavior could indicate that something about how a work process is executed has changed. Many reasons exist, including a worker perfecting a better technique which should be adopted by others, and erratic operation of or deteriorating machinery.

- *Example:* The standard deviation for the length of manually fabricated

longitudinals suddenly increases, decreases, or shifts.

Analysis: Examine how and by whom the longitudinals were fabricated.

Methods, particularly sequences, should be thoroughly analyzed.

Remedy: There could be many solutions, dependent upon results of the detailed analysis. One shipyard's response was to finish cut longitudinals before bending, i.e., eliminate end margins to permit grasping for bending at the ends. Following the mechanical bending process, line heating was introduced to bend the finish cut ends. Accuracy was improved (the standard deviation was reduced) and the wasteful margins were eliminated.

4.1.3. *Setting Accuracy Standards.* Data analysis quantitatively sets accuracy standards. For example, when erection joints are aligned, the achieved distribution of gap variations will, at the extremities of the distribution, show requirements for rework:

- cutting where a gap is too small or negative
- back strip welding or building on an edge where there is too much gap

As shown in Figure 8-21, when G_a is less than 0, minimal material is cut off to achieve the gap G_n , because it is cheaper to retain as much of the original material as possible. When G_a is more than 0, a minimal amount is built up to achieve the gap G_w , because the build-up process is expensive. Thus, G_n is always smaller than G_w .

The condition for avoiding rework is:

$$G_n \leq G_a \leq G_w$$

Therefore, by definition the lower tolerance limit is G_n and the upper tolerance limit is G_w . A standard range to be used as a goal for improving G_a can be established accordingly (see Figure 8-22).

4.1.4. *Modifying Distributions* Consider traditional rework for adjusting erection gaps. Cutting dominates, because costs for cutting are generally less per lineal foot than for back strip welding. The mean value of the pertinent distribution of gap variations favors the lower tolerance limit accordingly. Figure 8-23 shows this intentional bias and also shows the impact of shifting the mean value toward the upper tolerance limit. Because of the nature of normal distributions, the nominal increase in back strip welding is overwhelmingly offset by the substantial decrease in cutting required. Further, the prospects for exceeding the lower tolerance limit are reduced. Thus, analytically derived goals proposed by A/C engineers are based on actual data as collected and analyzed.

When an A/C system is implemented, operations managers benefit from detailed reports of productivity during hull erection. The reports relate total lengths of gas cutting and back strip welding to the total lengths of erection gaps. In a typical report for erection of a 167,000 DWT bulk carrier (see Figure 8-24), rework was required only for 32.6 percent of total gap lengths. The data specifying rework at erection are sufficiently detailed to permit the initiation of process analysis.

4.1.5. *Sequence for Analysis* Ongoing review of accuracy standards data is very important. The following procedure for analysis of data obtained during flat block assembly is typical:

- prepare separate histograms of variations for each characteristic, such as length, width, etc (see Figure 8-25)
- calculate the mean value, $\bar{x}$, and standard deviation, σ , for each characteristic
- use each standard deviation to determine how the data conform to the pertinent standard range (define standard range as $\bar{x} \pm 2\sigma$)
- when the data for a characteristic do not conform with the standard range

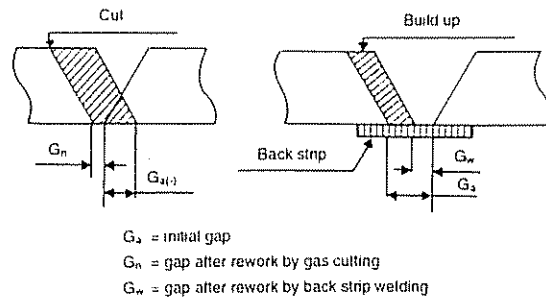


Fig 8-21 Analysis of rework at block weldings

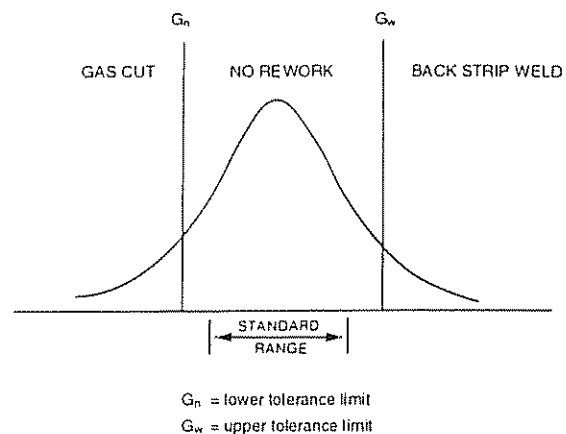


Fig 8-22. Normal distribution of erection joint gap

($\bar{x} \pm 2\sigma$ means conformance with 95 percent probability), A/C engineers confirm that the standard range is appropriate, investigate, and make necessary recommendations, such as adjusting excess allowance, changing methods, or supplementing worker training, or, alternatively, they may propose changes in the standard range which do not affect end product tolerances.

4.2 Urgent Analysis

In shipbuilding, it is not possible to completely eliminate variations which require rework. Moreover, no one can predict exactly when they will occur. Disruption is caused by the effects of such things as errors, accidents, and weather abnormalities, which dif-

fer from variations because their occurrences do not adhere to normal distributions. Despite their erratic nature, they too require organized responses and analyses to identify short-term or temporary solutions which minimize disruptions, and to subsequently achieve permanent means to prevent recurrence. The feedback path for these urgent considerations is included in Figure 8-20.

A possible preplanned response to a serious inaccuracy is to immediately summon

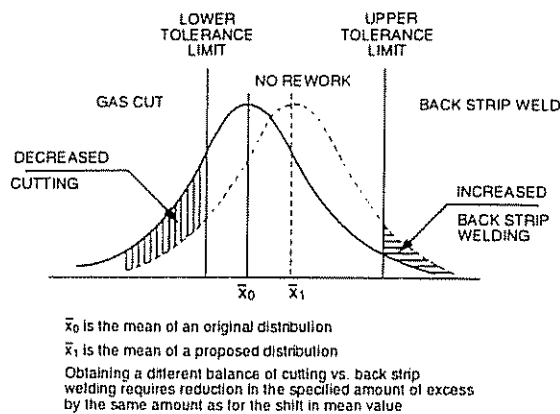


Fig 8-23. Shifting an erection joint gap distribution to control the type of rework required

select personnel who are familiar with the principles of A/C. This troubleshooting team of specialists for planning, executing, and evaluating meets where the inaccuracy exists to examine the evidence firsthand. Their job is to evaluate impact on work flow, recommend what, how, and when rework is to take place, minimize disruption, and collect evidence for identifying the cause. After taking temporary countermeasures for quickly restoring work flow, investigations continue for the purpose of devising permanent solutions.

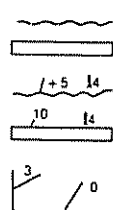
4.3. Control

Controls which assure that achieved accuracy conforms with an A/C plan for construction are important. They are classified as regular or special.

Because of the many different parts and subassemblies required, regular controls are applied to repetitive work processes. Typical regular control items in an ongoing A/C program, including their measurement frequencies, sample sizes, and standard deviations, are listed in Figure 8-26. Control charts for such regular usage were shown in Figure 8-3. Such charts are maintained by A/C

ANALYSIS REPORT FOR HULL ERECTION

	Erection Gap Length (M)	Gas Cutting Length	%	Back Strip Welding Length	%	Rework (%)
Upper Deck	1,548.2	452.3	27.4	65.6	4.2	31.6
Side Shell	797.8	203.8	25.5	53.2	6.6	32.1
Longitudinal BHD	652.2	324.0	49.6	34.0	5.2	54.8
Tank Top	431.8	27.3	6.3	17.5	4.0	10.3
Bottom Shell	1,453.7	344.8	23.7	102.5	7.0	30.7
Total Hull	4,883.7	1,325.2	27.1	272.8	5.5	32.6



Gas cutting
 Backing strip welding
 designates surplus of 5mm over 4m length
 designates gap of 10mm over 4 m length
 are position/dimension indicators

Gas cut When surplus was 3 mm or more
 Back strip weld When gap was 5 mm or more too wide
 Length 281M
 Breadth 48M
 Depth 28 2M
 Dead Weight 167.500 Tons
 Launching April 12 1977

Fig. 8-24(a). Hull erection rework analysis and report (continued in Fig 8-24(b) through (d)).

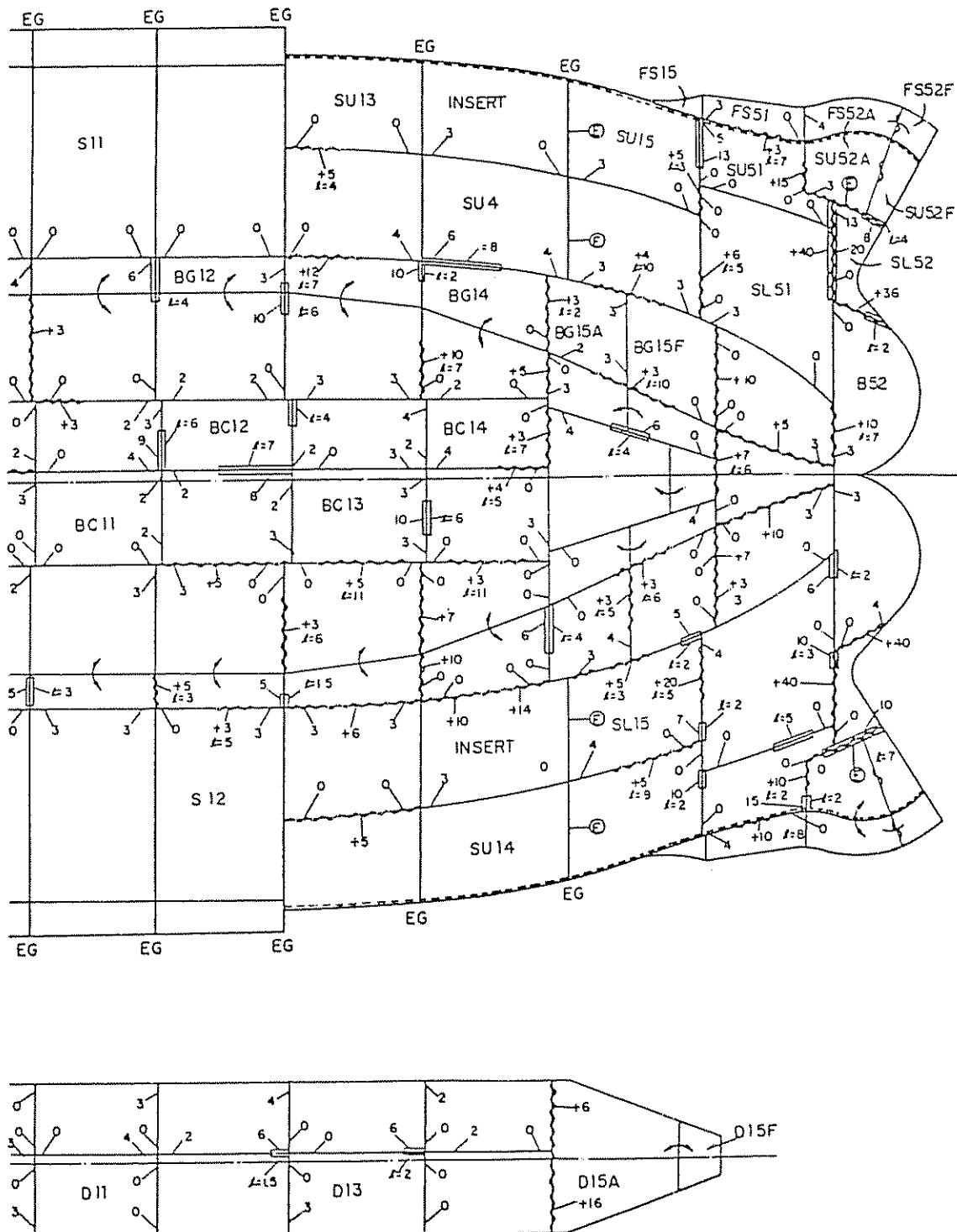


Fig. 8.24(d)

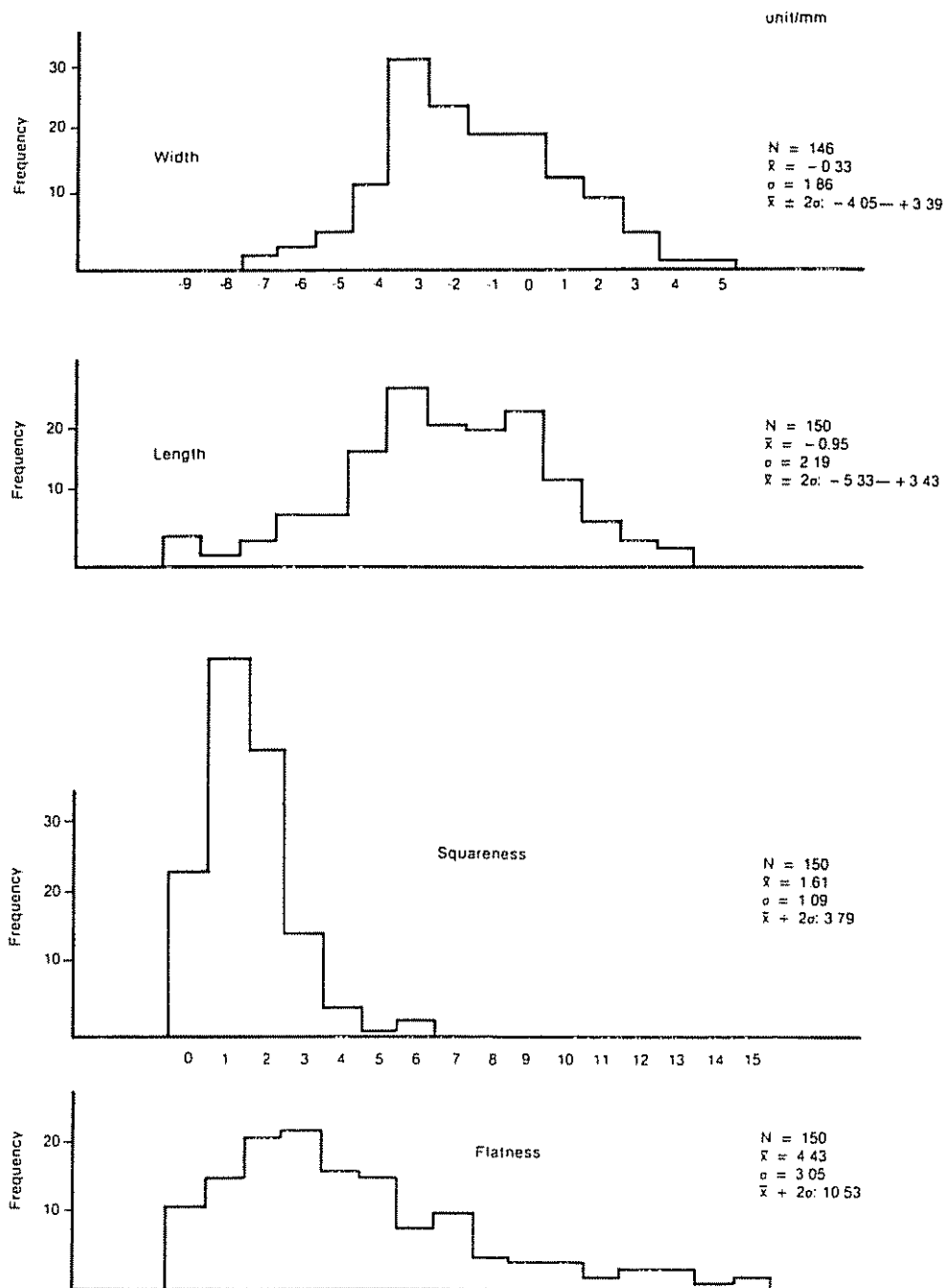


Fig 8-25. Histograms of variations of different characteristics

engineers for production control purposes. Once people become used to them, they provide guidance to everyone concerned, including workers and their supervisors. Therefore,

each such control chart is posted at its respective work station.

Special controls are based upon the accuracy condition of a hull upon completion. Nec-

essary vital points are defined and included in the A/C plan for a specified hull. When the hull is completed, members of the A/C group accumulate and analyze measurements that relate to predetermined vital dimensions. They look for accuracy trends which should be modified for further productivity improvements.

Statistically derived data which predict variations in block edges are not sufficient for depicting the actual status of each block. Erection planners are concerned with how the exact dimensions and configuration of every block compare with design dimensions. A position-dimension diagram (P/D) satisfies this need (see Figure 8-27). This information is needed to develop variation tables, which are used to determine where gas cutting and/or back strip welding is required (see Figure 8-28). Similar information, for the end positions of girders and longitudinals, is also

prepared for the same purpose (see Figure 8-29). Each P/D assumes that the rectangularity and overall dimensions and shape of the panel on which the block is assembled are within specified tolerance limits. The validity of P/D's also depends on conformance of control items such as those listed in Figure 8-26.

Effective control of accuracy is dependent on proper understanding of variation-merging equations such as those given in Figure 8-14. Too much focus on a merged variation, $\bar{z}$, is not worthwhile. It is more important to focus on each factor on the right side of each equation. If these factors are sufficiently controlled, nominal checks will suffice to confirm each merged variation. Some of these nominal checks, usually random samples, are useful for balancing alternatives such as gas cutting versus back strip welding, as shown in Figures 8-21 through 8-23.

5. Applications

5.1 Design

The hull block construction method developed naturally following the introduction of welding. Some shipbuilders changed their organization of structural drawings to suit. Appropriate drawing titles evolved, such as block erection plan, block assembly plan, sub-assembly plan, and parts cutting plan. These are more than traditional detail design drawings, because they associate classifications of parts and assemblies with specific manufacturing levels in production. They are, to some degree, work instruction drawings.

Design and material definition should be regarded as aspects of planning, and drawings should be further developed as virtually complete work instructions, including A/C work. Checking and recording should be clearly delineated as production work, just as much as marking, cutting, fitting, etc. By including A/C requirements, particularly vital points and dimensions and excess allow-

ances, excesses are adequately considered and are consistently applied, and the potential for human error is reduced. Loft, parts fabrication, and assembly workers no longer have to refer to separately prepared A/C requirements or depend upon recollections.

5.2 Mold Loft

Strictly speaking, loft processes should be subject to the same A/C scrutiny as marking and cutting in a parts fabrication shop. However, mold loft process variations are too small to significantly affect merged variation during parts fabrication. But loft errors (mistakes, omissions, etc.) are of concern because they disrupt the A/C cycle.

Errors cannot be treated with classical A/C theory, since they do not enter into variation-merging equations. Therefore, for A/C purposes, written procedures should be developed to address the classification of errors and methods for checking, recording, and ana-

lyzing them. Further, qualified people should be assigned as specialists to do the checking. Loft error lists and graphic representations of frequency of occurrence are control mechanisms that can be used (see Figure 8-30).

The mold loft should be regarded as a nucleus for A/C activities, because it generates most of what is used to achieve and maintain a specified degree of accuracy. Loft processes for producing N/C data, templates,

and other information formats should include essential A/C requirements, such as:

- locations of vital points
- calculated vital dimensions
- calculated special dimensions that facilitate assembly and checking work
- reference lines and checkpoints
- adequate marks for layout marking (while most are sufficient for snapping

Stage	Regular Control Item	Measurement Frequency	Sample Size	Standard Deviation (mm)
Template Production	Tape	Week	20	0.4
	Paper Template	20 Days	8	0.5
	Tin Template	20 Days	8	0.4
	Wood Template	20 Days	8	0.5
Part Fabrication	Cutting Plate by Flame Planer-Width	Day	8	0.4
	Cutting Plate by Flame Planer-Straightness	Day	All	-
	Finish Marking Plate Length	Day	All	-
	Finish Marking Plate Main Marking Line	Day	All	-
	Finish Marking Plate Right Angle	Day	All	-
	Bevel Angle for Auto Welder	10 Days	8	1.0
	Curved Plate Marking	Day	8	0.8
	Cutting Accuracy of Curved Plate	Day	8	0.8
	Shape Marking	Day	8	0.5
	Cutting Accuracy of Shapes	Day	8	0.8
	N/C Cutting Machine Plate Width	Day	8	0.6
	N/C Cutting Machine Plate Length	Day	8	0.5
	Cutting Accuracy of Internals e.g., Floor Girder in a Double Bottom	Day	8	0.8
	Cutting Accuracy	Day	8	1.5
Sub-Block Assembly	Accuracy of Fitting Stiffener	Day	6	0.7
	Straightening Deformation by Line Heating	Day	6	0.8
	Accuracy of Fitting Faceplate	Day	8	0.8
	Accuracy of Fitting Angle	Day	—	1/200
Block Assembly	Plate Length	2 Days	8	1.4
	Plate Width	2 Days	8	1.5
	Right Angle (Difference between Diagonals)	2 Days	8	1.2
	Reference Line	2 Days	8	0.8
	Position of Longitudinal Edge	2 Days	8	1.2
	Position of Transverse End	2 Days	8	1.5
	Accuracy of Through Piece	2 Days	6	1.5
	Accuracy of Curved Shell Web	2 Days	6	5/1000
	Curved Shell Plate Length (After Cutting)	3 Days	4	1.5
	Curved Shell Plate Width (After Cutting)	3 Days	4	1.5
	Curved Shell Plate Reference line (After Cutting)	3 Days	8	0.8

Fig 8-26. Regular control items.

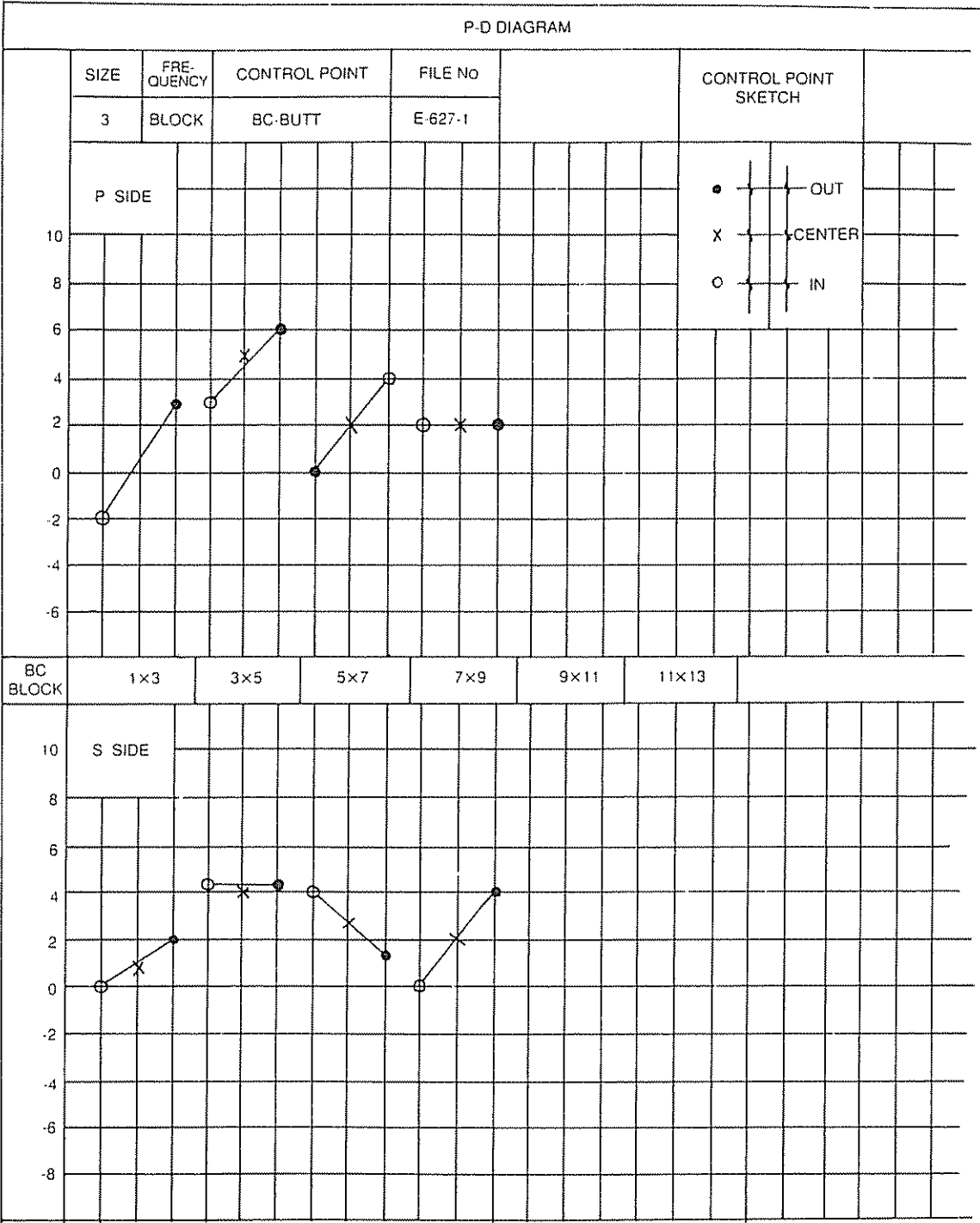


Fig. 8-27 Position dimension diagram

a chalk line, there is difficulty in identifying which marks associate with each other)

- excess already incorporated (A/C is enhanced when workers do not have to separately mark an excess allowance)
- bridging instructions to minimize warpage and shrinkage during gas cutting

5.3 Production Control

If only the terms *parts fabrication*, *subassembly*, and *block assembly* are coded in a marking system for interim products, it is difficult to relate a breakdown of vital points to a breakdown of a hull into interim products. Further classification of such products should be included in a marking system, so that each interim product has a unique identity by zone/problem area/stage. In other words, a fully developed product-oriented work breakdown structure is essential for effective A/C planning, executing, and evaluating.

Product orientation enables designers to respond more readily to production control requirements for work instructions. The latter are more than just detail drawings, because they define interim products and specific sequences for their manufacture. Organizing information by product helps designers to more readily respond to A/C requirements, including tolerance limits and vital points in work instructions. Work instructions are the most universally used documents. Therefore, providing such information in work instructions facilitates mutual understanding of A/C requirements and more efficient execution by loft, parts fabrication, and assembly workers, as well as by personnel with A/C responsibilities.

In addition, product orientation permits sufficient classification of the many part and subassembly geometries to relate them to specific work processes. This association is critical for obtaining valid A/C data. Otherwise, work circumstances are insufficiently controlled, and virtually no data sample will

approximate a normal distribution. Quantitative A/C techniques would, therefore, not be applicable.

5.4 Parts Fabrication

N/C gas cutting is almost universally applied by shipbuilders, but there are still situations where semiautomatic cutters are useful supplements to N/C installations. More variation is probable in a semiautomatic process, and therefore A/C requirements should be different. However, there are common considerations when accuracy performances need to be enhanced. Human engineering aspects apply, even for very advanced N/C systems. Shrinkage allowances should be specified differently for different part classifications, such as parallel edge part, internal part, etc. Kerf tolerances should be specified. Maintenance and accuracy checks, more complicated for an N/C machine, should be performed regularly and frequently. Worn torch tips should be replaced and others cleaned. As heat deformation problems have not been totally solved, measurement data should be accumulated on the effect of various cutting sequences, bridge restraints, etc. A/C engineers should be alert for cutting alternatives, such as lasers, which can be focused and can perform with narrower kerfs, less heat input, and thus less shrinkage and distortion.

5.5 Subassembly

Methods to control deformation, such as pre-tensioning, preheating, and specifying welding sequences should be practiced. Regarding shrinkage, consider the panel for the subassembly shown in Figure 8-31. When the large plate is gas cut, shrinkage Δ_1 occurs, because no bridges were provided across the cut-outs. Additional shrinkage Δ_2 occurs when the large plate is welded to the small plate. Without a shrinkage allowance, the combined shrinkage $\Delta_1 + \Delta_2$ could necessitate rework, such as making the cutouts deeper during block assembly.

QTY 100 10	PARTIES CONCERNED		DESIGN	MOLD LOFT	FIELD SHOP	A
	DEFECT TYPE	SHIP NO DETAIL				
E.P.M. (INTERNAL STRUCTURE)	FORM	JOINT LINE				
		BRACKET				
	FITTING	POSITION				
		SLANT				
		NO SLANT MARK				
		WRONG MOLD LINE				
	SCALLOP	INDICATION				
		MARKING				
		CUTTING				
	BEVELING	INDICATION				
		JUNCTION				
		CUTTING				
	HOLE	POSITION				
		SIZE				
		CUT				
	SLOT	SYMBOL				
		WRONG DIRECTION				
	BASE LINE	NO MARK				
	Q'TY	SHORT				
	NO MARKS OF PARTS					

QTY 100 10	PARTIES CONCERNED		DESIGN	MOLD LOFT	FIELD SHOP	A
	DEFECT TYPE	SHIP NO DETAIL				
SIZE LIST (SHAPE, FC, FB)	SIZE	INDICATION				
		LONGER				
		SHORTER				
	BEVELING	INDICATION				
		CUTTING				
		NO TAPER				
	SCALLOP & DRAINHOLE	MARK				
		INDICATION				
	SERRATION	CUTTING				
	SNIP	INDICATION				
		CUT				
	SUB TOTAL					
	TOTAL					

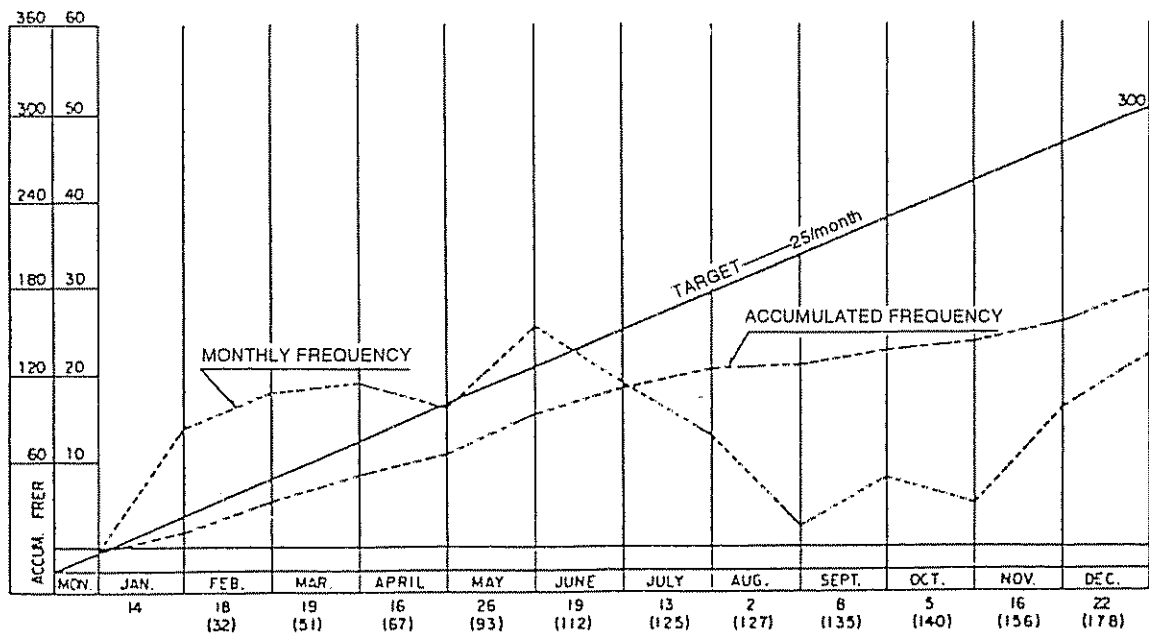


Fig. 8-30 Mold loft error list and frequency chart.

To overcome such shrinkage, the two plates should be welded before gas cutting, bridges should be used across cutouts, all stiffeners and faceplates should be fitted to the web before welding commences, and welding should conform to a prescribed sequence. Further, deformation such as that caused by welding should be diminished by pretensioning and/or removed by line heating.

Fitting processes for subassembly are mainly performed manually. Where A/C is ongoing, there is close association between supervision of subassembly work and the A/C engineer assigned to the subassembly section. In a small shipyard, the A/C engineer might be assigned to the hull construction department. Because of preoccupation with variations in each work process and how they merge, the A/C engineer readily detects situations where simple jigs enhance both accuracy and productivity. Many such jigs should be used.

5.6 Block Assembly

All of the preceding suggestions for subassembly should also be applied in block assembly. During this stage, because it is just before erection, checking for accuracy is very critical. The checks should include alignments of platen and pin jig foundations and means for positioning plates to form the panels upon which blocks will be assembled. For curved blocks, pin jig heights should be checked. After a curved panel is assembled, marked, checked, and finish cut, the positions of its curved edges should be carefully checked. Further, simple jigs should be used to fix end positions of longitudinals and their angle of inclination.

5.7 Standardization

Standards imply conservatism. Quite the opposite is true for A/C matters. A standard is simply a description of an authorized and currently practiced condition which is a baseline for comparing proposed improvements.

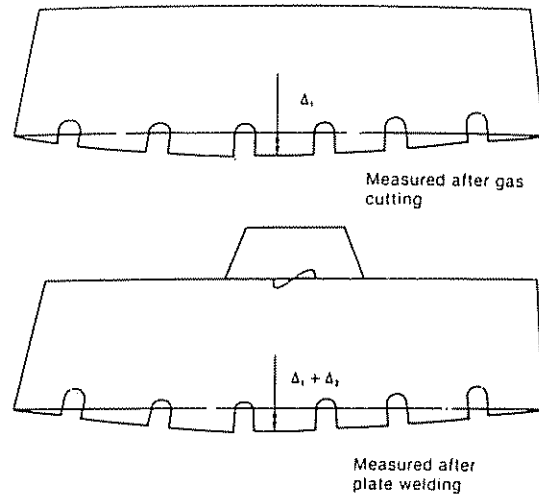


Fig 8-31 Weld shrinkage analysis based on work sequences.

Thus, standards are a means for a shipyard, as an entity, to know what it is doing and where it is going in shipbuilding technology matters. Adequate standards, in numbers and content, and sufficient specialists to modify, create, and cancel standards, are necessary for continuously improving productivity. Many shipbuilding problems can be solved by developing standards for accuracy, excess and shrinkage allowances, work flows, and work processes.

5.8 Accuracy Standards

Because accuracy standards are expressed as both standard ranges of accuracy normally encountered and tolerance limits beyond which rework is required, they can describe a shipyard's potential for complying with tolerances specified for end products.

Just as much as accuracy standards are baselines for evaluating proposals to improve productivity, they are baselines for improving accuracy in an end product. If accuracy standards and an ongoing A/C organization which supports them are approved by a classification society, reapprovals for additional ship construction are usually unnecessary.

5.9. Excess and Shrinkage Allowance Standards

Excess is an essential concept for successful application of A/C to hull construction processes. However, the amounts should be based on analyses of actual data which reflect the shipyard's experience. Statistically derived excess standards are based on the probability that, for a high percentage, no rework will be required. Thus, applying excess is an attempt to compensate exactly for normal variations caused by work processes which lead to variations in joint gaps to be welded during erection. There must be understanding that a small percentage will require rework by gas cutting and/or back strip welding.

Excess is generally thought of as a means for extending the edge of a plate to compensate for shrinkage. However, its use elsewhere should be specified, such as for facilitating the fit of stiffeners between longitudinals (see Figure 8-6).

5.9.1. Ways to Distribute Excess versus Assembly Sequences. Sequences for assembling a block, consisting of a panel stiffened by longitudinals and webs, can be classified as "egg crate" or "weld longitudinals to panel first." The work sequences are different, as shown in Figure 8-32. Thus, the shrinkages caused by welding are sequenced differently. This is important, because restraints are different, the heat input for different welds varies, and regions that have been shrunk before do not shrink the same amount, even for the

same heat input, during subsequent welding. Thus, the pertinent data that shipbuilders collect should be classified to match one or more of the four assembly alternatives depicted in Figure 8-33.

5.9.2. Elements of Shrinkage Allowance. Shrinkage allowance is required to maintain the specified shape and dimensions at hull erection. The amount of shrinkage allowance for gas cutting, welding, and/or line heating should be derived from data collected during shipyard operations. Shrinkage allowance is required for the following operations (see Figure 8-32):

- fillet welding internal members to shell plates (A), where shrinkage occurs in the direction normal to the welding line
- removing welding-induced distortion by line heating after assembly work (B), such as removing opposite-side indentations caused by fillet welding internal members, shrinkage occurs in the direction normal to the heating lines
- welding plates to form the panel on which a block is assembled (E)
- fillet welding stiffeners (flat bars and brackets) to internal members such as a web plate (a)
- line heating on subassemblies, such as webs, to remove the indentations caused by welding (b)
- welding plates of internal members such as webs (E)

"EGG-CRATE" WORK SEQUENCE	"WELD LONGITUDINALS TO PANEL FIRST" WORK SEQUENCE
1 Panel Assembly (E)	1. Panel Assembly (E)
2 Panel Marking	2. Panel Marking
3 Egg-crate Assembly (a,b,e)	3. Longitudinals to Panel Welding (A)
4 Egg-crate to Panel Welding (A)	4 Other-internals Welding (A.a.b.e)
5. Line Heating (B) if necessary	5 Line Heating (B) if necessary

Fig. 8-32 Alternative assembly sequences.

EXCESS DISTRIBUTION	ASSEMBLY SEQUENCE
Only At Panel Edges	Egg-crate
	Weld Longitudinals To Panel First
Proportionally Throughout	Egg-crate
	Weld Longitudinals To Panel First

Fig 8-33. Excess distribution must be determined for each alternative assembly sequence.

Shrinkage allowance is also required to compensate for welding and line heating other miscellaneous interim products, including parts, blocks of special shape, etc.

5.9.3. *Ways to Distribute Excess.* There are two practical ways to predict the excess needed to offset shrinkage as described in the foregoing:

- provide excess amounts only at edges of a block without regard for apportioning excess between block internals, causing the final positions of the internals to be different from the specified design (the dimensions needed for layout are readily obtained from design drawings)
- distribute excess proportionally, taking into account shrinkage rates expected to be caused by each work process and the relative spacing of block internals from each other and panel edges, which requires recalculating the dimensions needed for layout, but produces final positions of internals that more accurately conform with design

5.9.4 *Standards for Work Processes and Information Flow.* To establish effective standards, the role of each parts fabrication shop and assembly section must be carefully reviewed

for its impact on production process flow. The inputs and outputs of each should be clearly defined and consistent with a single A/C system. In other words, everything on the right side of the variation-merging equation must be compatible to obtain the best productivity for the entire hull construction process.

There cannot be dependence on merely parochial knowledge. Written work processes that relate to each other are essential for achieving specified accuracies and uniform flows of work and information. Standard processes also make it easier to change jobs and are a great aid for training. When a process standard is revised to incorporate an improvement, others related to it should be reviewed and/or revised as necessary.

The following guidance applies to standards which should be established:

- standard practices for
 - work instructions
 - lofting
 - parts fabrication (marking, gas cutting, bending, line heating)
 - subassembly
 - block assembly
 - shipwright work
 - welding
- A/C contents of standards
 - checkpoints
 - dimensions to be checked
 - checking methods
 - tolerance limits
 - checking procedures for jigs and machinery
 - feedback and remedial measures
- examples of standards for flat block assembly
 - plate arrangement (positioning, match mark)
 - welding (misalignment, gap)
 - panel marking (diagonal length, width, straightness)
 - holes

- examples of standards for curved block assembly
 - supporting jig (normality, height)
 - plate arrangement (jig position)
 - datum line for joining
 - block marking (four edges, diagonals)
 - holes
- examples of standards for fitting
 - elimination of welding bead rise where internals cross panel joints
 - gas cutting (notch, roughness, check line)
 - position of end of web
 - position of end of frame
 - angle of internals relative to a panel
 - collar plate fitting
 - misalignment and gap where internals join each other
- examples of standards for grinding
 - bead removal for rework
 - bead removal to free temporary fitting
- examples of standards for line heating
 - block interface edges
 - specified temperatures
 - specified locations
 - fairing

5.10. Measuring

Some variations are inevitable due to differences in:

- measuring methods
- environments
- work circumstances
- reading judgments, etc.

The results of analysis indicate that measuring variations does not significantly contribute to merged variation. However, each shipyard should verify its own measuring capabilities.

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SHIP CONVERSION, OVERHAUL, AND REPAIR

1. Introduction

The ship conversion, overhaul, and repair industry is concerned with working on ships during their service lives:

- changing their configurations so they can do better jobs or different jobs (conversion/modernization)
- generally and extensively bringing them back to an almost like-new condition (overhaul)
- maintaining the equipment and hull integrity of the ship, repairing or replacing damaged and worn parts (repair)

Also discussed in this chapter is what happens at the end of a ship's service life—deactivation or scrapping. The characteristics of the various repair markets are presented, along with recent innovations in ship maintenance and repair.

1.1. Life Cycle of a Ship

A ship in service is subjected to operational wear, to deterioration from exposure to harsh environments, and to damage from heavy weather and unplanned encounters with solid objects. The basic actions taken to counter these effects and maximize the operational readiness of the ship during its service life are illustrated in Figure 9-1.

The scope of work and timing of each of these actions is determined by one or more of the following: (1) rules of the classification societies and regulatory bodies, (2) maintenance philosophy of the owner, and (3) economic, market, and safety considerations.

Planned Maintenance. This is a programmed cycle of regular, scheduled maintenance and repair based both on direct inspection and equipment failure history. It also includes periodic surveys by classification societies and regulatory agencies.

- Non-dry dock — frequent (usually annual) pierside inspection and repair involving topside work where a dry dock is not needed for access; also includes underway maintenance
- Dry dock — periodic major maintenance involving inspection and repair of the underwater hull, propellers and shafts, rudder, thrusters, hull coatings, cathodic protection, sea chests, and other underwater items; usually also includes all the work done in a non-dry dock maintenance and small to medium-sized configuration changes planned for the ship (includes overhauls)

Unscheduled Repairs. This type of repair becomes necessary when there is an unexpected equipment failure or fouling, storm damage, collision damage, fire, or any other

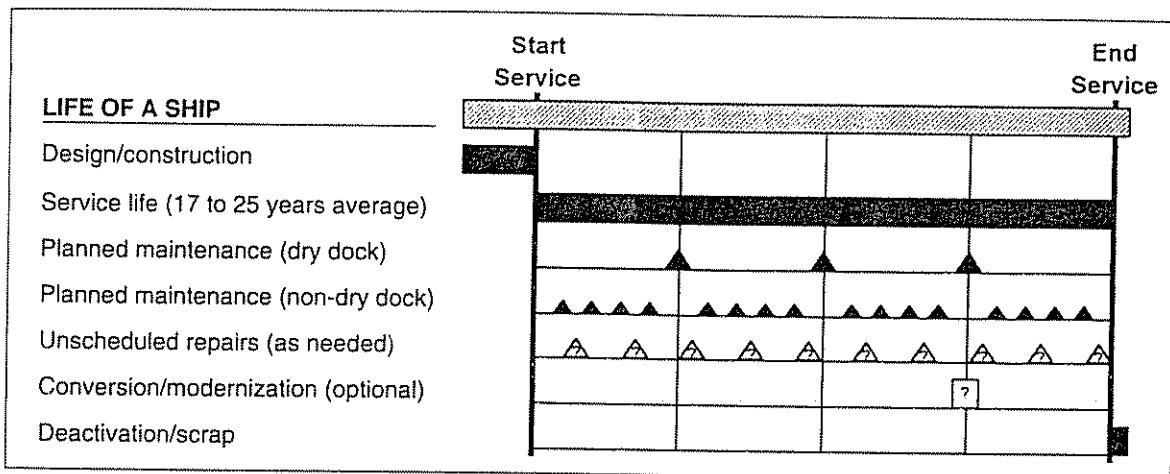


Fig. 9-1 Maintenance/repair life of a ship.

event that compromises the safety of the ship or its ability to perform its mission. It may require dry-docking, depending on the nature and extent of the damage.

Conversion/Modernization. Occasionally, as a ship grows older or market needs change, it may make economic sense to the owner to convert the ship for a different mission or to modernize it to extend its service life. Conversion might involve lengthening a ship with a new midbody, changing the bow, re-engining, changing the configuration to handle a different kind of cargo, adding cranes for self-loading, or even changing a cargo ship into a hospital ship. Modernization usually involves upgrading most of the systems on a ship, including hull, propulsion, electronics, and habitability to significantly extend the life of the ship and meet the latest safety standards.

Deactivation/Scrapping. At the end of the economical service life of a ship, the owner has to determine how to dispose of it. This can sometimes occur earlier in a ship's life if market conditions change drastically and the ship is highly specialized, such as a liquefied natural gas carrier. Some ships, especially in the military, are deactivated and stored for possible later use. Others are broken up for the scrap or resale value of their materials and equipment.

1.2. Size and Scope of the Industry

Ship conversion, overhaul, and repair represents an important part of the U.S. shipyard market in terms of volume, profitability, and market stability. This market supported an employment level of almost 30,000 people in the United States during the decade of the 1980s. [1]

In terms of dollar value, this work represented nearly 33 percent of all shipwork in 1987. A breakdown of the market between military and commercial and between conversion and repair (including overhaul) is shown in Figure 9-2. [2] The conversion, overhaul, and repair market maintained a combined level of \$3 to \$4 billion in the United States through the early 1990s. [2] Of the total, over 70 percent of this amount has been directly related to ships in service for the use of the U.S. government (Navy or Military Sealift Command [MSC]). Current downsizing of the U.S. Navy from 600 ships in 1985 to 346 ships by 1999 will have a significant impact on the naval portion of the repair industry.

Virtually all the new-construction yards also convert, overhaul, and repair ships. As the ship construction market has decreased, conversion, overhaul, and repair have become increasingly important to most of these yards. Many have had difficulty in adapting to the different requirements of the repair mar-

ket. These requirements feature a smaller overhead organization, a multiskilled, flexible work force, and the ability to respond rapidly to emerging conditions that effect a ship's operating schedule. Disruption of the planned ship construction schedule sometimes occurs when urgent, unscheduled ship repair work arrives at the shipyard and competes for the attention of the best managers and craftsmen. Construction yards sometimes use separate facilities or organizational units for overhaul and repair activity to avoid these problems.

Some shipyards specialize in the conversion, overhaul, and repair market to the ex-

clusion of new construction. This includes the eight publicly owned Navy shipyards that have been dedicated to conversion, overhaul, and repair for over three decades. (Three, and perhaps more, of these eight public yards will be closed as U.S. forces are downsized following the end of the Cold War.) There are also smaller companies without full-service shipyard facilities that team with specialty subcontractors and, sometimes, with other shipyards to participate in this market.

1.3. Nature of the Industry

Conversion, overhaul, and repair jobs come in all sizes and degrees of complexity. Each type of work may have different facility, planning, and management requirements depending on its size and complexity. See Figure 9-3. Facility requirements may range from portable tools to a full-service shipyard; planning requirements from simple, single system to complex zone technology; and management requirements from functional, single trade to sophisticated project teams working in a matrix relationship with a full-service shop and support organization. Matching the optimum approach with the individual job will yield the most effective results.

There are both similarities and differences between ship construction and ship conver-

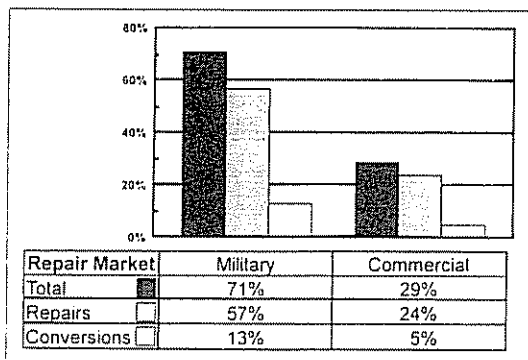


Fig 9-2. Breakdown of U.S. ship repair market (from *Census of Manufacturers*, 1987).

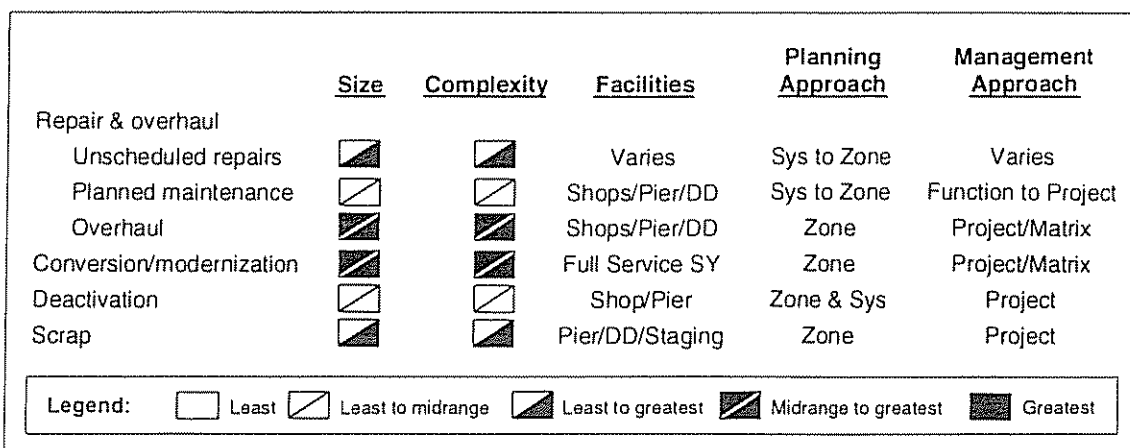


Fig 9-3. Nature of the industry

sion, overhaul, and repair. Similarities include application of essentially the same manufacturing and construction processes, using much of the same equipment, tools, facilities, material, and worker skills. The most important differences involve time to complete the work and certainty of work scope. Construction follows a carefully laid-out plan for a known scope of work over a fixed amount of time. Conversion, overhaul, and repair must accomplish a mixture of known and unknown work on an already existing ship, while minimizing out-of-service time for that ship.

Out-of-service time for a ship is very expensive to its owners. Thus rapid completion of work may be more important to an owner than low price. This is especially true in the cruise ship industry, where large crews of service personnel and vast stores of perishable supplies make operating costs so high. Much emphasis is placed on creative approaches to minimize the ship's downtime, e.g., use of riding teams to repair a ship as it continues its route, use of the ship's ballast system to achieve extreme heel or trim conditions to gain access to underwater damage without having to go on a dry dock, or removing equipment in one port and replacing it in another.

A major difficulty in minimizing a ship's downtime is that the scope of the required repair work is not often completely known. Inspections are conducted at sea, logs are kept, and various maintenance philosophies implemented, but much repair work always has to be identified after the job starts, when the machinery, tanks, and other inaccessible places are opened and inspected.

The uncertainty of the work scope means that the shipyard needs an organization that can flexibly respond to on-site information and resolve problems that may not become apparent until the work is underway. This requires craftsmen who are cross-trained and multiskilled, managers working within an empowered project management team, and a

flexible planning approach appropriate for the size and complexity of the job.

The uncertainty of conversion, overhaul, and repair makes work organization for group technology (GT) more difficult to achieve. However, the longer lead time available for planned maintenance and the larger known work scope for overhauls and conversions allow use of a zone technology approach with repeatable work processes for some tasks. Consequently, project managers and planners must look for opportunities to use group technology, while remaining vigilant for changes occurring throughout the course of the job.

1.4. Marketplace Characteristics

The three primary markets in the conversion, overhaul, and repair industry are for commercial ships, military ships, and ships that are owned by the government, but are built and maintained to commercial standards. These three markets are discussed below.

1.4.1. Commercial Market

Owners of commercial ships are businessmen whose purpose is to provide a service to people who are willing to pay enough for that service so that the businessman can make a reasonable profit. Therefore, except for the classification society and regulatory agency requirements, the drivers in this market virtually all revolve around cost.

Cost of ship maintenance and repair goes well beyond the actual cost to have the work accomplished. It means the cost impact to the overall operations. Often the most important costs are caused by the out-of-service time for the ship. These can include:

- Impaired service and loss of schedule credibility with customers
- Loss of business anticipated in upcoming ports
- Providing opportunities for shipper's competitors to take away customers and penetrate market

- Damage to on-board cargo if it is perishable
- Unproductive crew costs
- Un-defrayed overhead costs

As can easily be seen, the decision on how much and how often to repair and maintain ships can be a complicated balancing act of competing needs. Of course, postponing needed repairs can sometimes lead to more serious problems that might result in even greater out-of-service time. Frequently the naval architect or chief engineer for a shipping company is responsible for giving the owner the technical advice needed in this decision-making process to balance one type of cost against another.

The business side of this decision is made more difficult by the intense competition in the shipping industry. The shipping market has for some time been extremely competitive, especially with the participation in trade routes by countries that heavily subsidized their merchant fleets. The heavy competition means less money available for all aspects of shipping operations, including repair and maintenance. However, the competition is also forcing new ideas and technology, and entrepreneurs are finding ways to provide better, faster, more reliable, and more secure service.

Much of the routine maintenance work on a ship is done as part of the planned maintenance program described in Section 3.2 of this chapter. The part required by classification societies and regulatory agencies will be done according to their rules. Other routine maintenance will be done in accordance with the owner's maintenance program. Such programs can vary widely, but will usually contain the following:

- Record keeping on performance of major equipment
- Records of any equipment failure
- Records of all underway maintenance and repair

- Inspections by in-house engineers or subcontractors
- Definition of work package and development of specifications
- An invitation for bids from prospective contractors requiring both a fixed price and a promised delivery date (usually guaranteed by a liquidated damages clause in the contract that requires the shipyard to pay the ship owner a pre-established amount for every day the ship is late)
- Selection of a contractor based on best business judgment; sometimes an owner may develop a relationship of trust with a shipyard that has more value than low price

Most shipowners use their own way of writing specifications to define the work and their own contract terms to control the work. Seldom are they similar or coordinated between owners. During the work, the owner is usually represented by a port engineer or other agent who makes technical decisions within limits established with the owner, interprets the contract and specifications, inspects and approves the work, and approves progress for invoicing. For larger jobs, such as overhauls, conversions, and modernization, the owner may have a whole team of representatives at the shipyard to oversee its interests.

Just as the shipowner is a businessperson first and foremost, so are the shipyard owners. They are also providing a service to make a profit. Virtually every contract they deal with is different. The specifications are in different formats, and the shipowner's representatives are experts at interpreting their own documents to their own advantage. Therefore, it is critical for the shipyard or repair contractors to have management people who can also read and interpret different kinds of specifications and a contract administrator on the project team who can protect the shipyard's interests and help the team

understand the contract requirements. Managing the contract well is at least as important to the financial success of the job as managing the work well.

Repair and maintenance programs for commercial ships can be executed in many various ways depending on the owner's maintenance philosophy, business approach, and the scope of the work. Some shipowners prefer to perform as much of their maintenance as possible with their own people. They may have shops in strategic ports or teams that can fly with their tools to wherever the ship is berthed. These teams may perform maintenance tasks both in port and underway and may prepare the ship in advance of in-port maintenance.

Some shipowners establish maintenance contracts with companies that provide repair crews whenever necessary and oversee shipyard contracts. They may also provide

services extended to include analysis of operating records, periodic inspections, spare parts storage, and most other aspects of managing ship maintenance programs. The maintenance contracts may cover a single ship or a fleet of ships.

Some shipowners contract for most repair and maintenance services on an as-needed basis. They may use topside repair companies when no dry-docking is required or full-service shipyards for larger, more complex jobs.

1.4.2. Military Market

The U.S. Navy ship repair and modernization market is a large and highly competitive business. The Navy's budget has been declining in recent years due to the changing world situation and the resulting decrease in fleet size. The FY94 budget request for ship repair and modernization was \$2.8 billion, a decrease of approximately 20 percent from

U.S. Navy Repair and Modernization Budgets of Active and Reserve Ships, FY 1990-94 (in millions of dollars)					
Item	1990	1991	1992	1993	1994
Public Yards	2,913.8	2,521.9	2,719.1	2,390.3	1,595.8
Private Yards	1,734.5	1,310.8	1,339.3	1,104.3	802.1
Competition	(*)	(*)	(*)	(*)	393.5
Total	4,648.3	3,832.7	4,058.4	3,494.6	2,791.4
* Data included in public and private yard budget numbers NOTE: Does not include other program costs SOURCE: U.S. Department of the Navy, based on FY 1994 Congressional Budget.					

Navy Shipbuilding and Repair Budgets, FY 1990-94 (in millions of dollars)					
Item	1990 (1)	1991 (1)	1992 (1)	1993 (1)	1994 (2)
Shipbuilding & Conversion	11,541.2	8,751.2	6,713.2	5,853.2	4,294.7
Ship Repair & Modernization	4,648.3	3,832.7	4,058.4	3,494.6	2,791.4
Total	16,189.5	12,583.9	10,771.7	9,347.8	7,086.1
(1) Appropriated (2) Requested SOURCE: U.S. Department of the Navy, based on FY 1994 Congressional Budget.					

Fig 9-4 U.S. Navy shipbuilding and repair budgets

the previous year (see Figure 9-4.) [3] This budget request is about 30 percent lower than the FY92 appropriation and about 40 percent lower than the FY90 appropriation.

The size of the Navy repair and modernization budget is driven primarily by external national security threats, potential war or conflict scenarios, and fleet operating requirements. The budget is also influenced by political budget constraints and the rising cost of modernization, conversion, and repair efforts.

The U.S. Navy has a maintenance philosophy and strategy that are tailored to each class of ship. These philosophies have evolved over the years with engineered maintenance cycles for each class of ship appropriate to its design characteristics and operational requirements. The cycles provide regular opportunities for modernization to meet constantly changing external threats during the life of the ship. Several classes of ships within the U.S. Navy have adopted a phased maintenance approach, whereas other classes of ships are maintained on a strict cycle of regularly scheduled overhauls and modernization periods.

The traditional maintenance cycle has periodic depot-level maintenance periods where the ship is not available for operations for two to three months. A more extensive overhaul and modernization period of 6 to 14 months is usually scheduled several times in the ship's service life. The Navy identifies the work to be done based on established requirements for each ship class and an extensive record-keeping, inspection, and engineering analysis program. All this information is processed and converted to a set of specifications in one of two standard formats, one for naval shipyards and one for the Supervisor of Ships to use for bidding and managing Navy repair work done by private shipyards. The Navy then either assigns the work to a naval shipyard or enters into a contractual relationship with the selected private shipyard for

the accomplishment of this work. Navy specifications and contract language are extensively standardized but are also very complicated due in part to heavy dependence on standard references.

The innovative phased maintenance approach is based on the development of a maintenance plan for the needs of a class of ship over an extended period in the life of the ship (usually 48 to 54 months). The Navy then evaluates proposals from a group of participating shipyards and enters into a cost-plus contract with the successful shipyard to identify, specify, plan, and execute these maintenance actions. The work scope is not defined ahead of time by the Navy in order to prepare a bid specification. Since a long-term contract exists, it is jointly developed by the Navy and the shipyard working together, making compromises as necessary to meet both the maintenance needs of the ship and the operating needs of the fleet. Some work might be deferred until a later availability to allow the ship to meet its operating commitments. One of the unique features of this approach is that it involves one shipyard for an extended period in the life of a group of similar ships, allowing it to build familiarity and expertise with those ships, develop lessons learned in the maintenance of all the similar equipment, plan for the execution of the maintenance actions during the most advantageous time for the ship (not the shipyard), and maintain spare parts and material between availabilities for emergency work.

The U.S. Navy's primary resources for execution of ship repair and modernization are 36 privately owned shipyards (down from 45 in 1992), eight publicly owned naval shipyards (three of which are scheduled to close by 1996), and two Navy-owned ship repair facilities.

Private shipyards must prequalify to do most Navy repair work. For work on larger, more complex ships, private yards must qual-

ify for a Master Ship Repair Agreement (MSRA). The yard's facilities, planning approach, and management must meet Navy requirements. For work on smaller, less complex ships and boats, a shipyard without waterfront facilities can qualify for an Agreement for Boat Repair (ABR). The U.S. Coast Guard uses a similar system to prequalify shipyards to work on its vessels and it has a small repair yard of its own.

The Navy also relies on an extensive internal infrastructure to conduct maintenance outside of the shipyard environment during the ship's operating cycle. These assets include:

- ship's crew
- tiger teams (similar to commercial riding teams)
- Intermediate maintenance activities that perform maintenance more demanding than ship's force level but not as complex as the major alterations and complex repairs assigned to shipyards

1.4.3 Quasi-Commercial Market

This is a market characterized by government-owned ships that are built and maintained to commercial rather than military

standards. It plays a significant role in the conversion, overhaul, and repair industry in the U.S., where many government agencies own ships but contract with private companies for their upkeep.

MarAd's National Defense Reserve Fleet (NDRF) and the Navy's Military Sealift Command (MSC) make up the bulk of this market. By 1999, MarAd's 96-ship Ready Reserve Force (RRF) is expected to grow to 140 ships. MSC currently has 152 ships. Other agencies with their own ships include the Army Corps of Engineers, the National Oceanic and Atmospheric Administration (NOAA), and the National Science Foundation.

The main driver in this market, other than the applicable classification and regulatory requirements, is government policy. The various agencies establish their own rules, but Congress controls much of what happens through its power to set budgets and fund programs. Contracting is done in accordance with government regulations, which usually means that the low bid wins a fixed-price contract for a defined scope of work. Maintenance providers are generally private full-service shipyards or topside ship repair companies. Naval shipyards have occasionally done work on these ships.

2. Selecting an Approach

Ship repair is a classic example of the job-shop form of production organization. It is a highly labor-intensive and skill-intensive activity with only limited potential for automation. Much of the work is done aboard ship, and consists of rip-out and refitting steel, pipe, machinery, or wiring to existing systems. The labor-intensive nature is also due to many parts being manufactured or rebuilt in-house, instead of being purchased new, as in ship construction.

Each job is unique, but to better understand how to approach the many different

types of repair situations we will focus this discussion on the following factors:

- size
- complexity
- facility requirements
- planning approach
- management approach

The combination of size and complexity of any conversion, overhaul, or repair job should dictate the approach taken by the contractor. Larger, more complex jobs tend to require

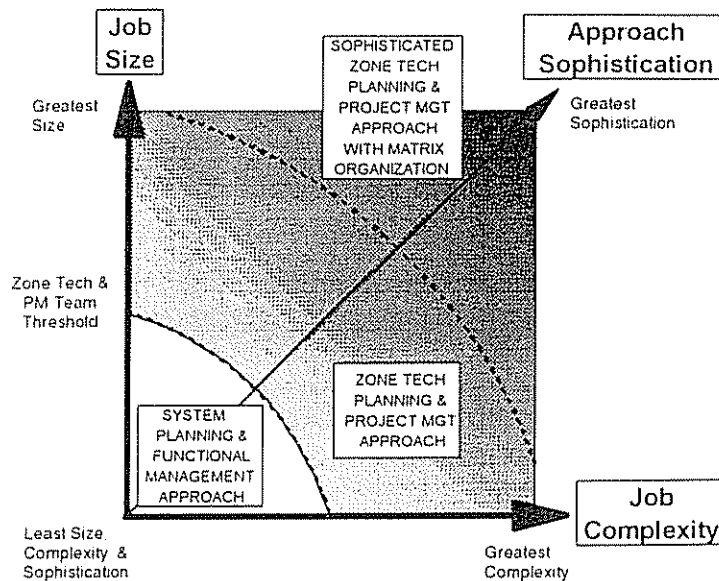


Fig 9-5. Approach selection criteria.

more extensive facilities and management organizations. They also lend themselves to the use of some form of zone technology approach and sometimes a limited amount of group technology. Smaller, simpler jobs can often be effectively executed with fewer facilities, less sophisticated organizations, and on-the-job planning. Where the threshold lies for using more sophisticated planning and management approaches is a matter of judgment, resulting from an evaluation of each job, as shown in Figure 9-5.

The size and complexity of a job serves as a guide for choosing the most efficient approach to that job and, in some cases, even limits which companies are capable of pursuing the contract, as some companies specialize in a narrow range of approaches. Large shipyards may find that providing teams to pursue small emergency repairs is disruptive and not economically feasible. Small companies may find that organizing and managing a large team to pursue major overhauls is too cumbersome, financially risky, and difficult to control. Rather than attempting to be all things to all people, some companies

try to be most competitive in a particular niche of the market

2.1 Facilities

The facilities of a full-service shipyard used for conversion, overhaul, and repair are very similar to those of new-construction shipyards. In fact, shipbuilding yards frequently compete for conversion, overhaul, and major repair jobs that require such facilities.

The primary differences involve proportioned utilization of facilities. In a new-construction shipbuilding yard, steel processing, fabrication, and assembly form the core around which other processes are organized. In conversion, overhaul, and repair, steel work is but one of several processes whose priority is established by the nature of the job. Often outfitting tasks are more extensive and controlling than structural work. The outside machine shop serving the machinists working on the waterfront, the pipe shop, or the electrical shop may assume a priority role. Services to piers and docks assume a greater importance because, in addition to supporting shipyard workers, they are

also used to keep many of the ship systems on-line during the repair activity in support of the ship's crew.

A full-service shipyard may include a range of dry-docking capabilities, such as:

- large graving docks capable of servicing VLCCs, ULCCs, aircraft carriers, and other large vessels
- medium-size graving docks for dry-docking medium and small ships, sometimes more than one at a time
- floating dry docks for smaller ships and submarines, and to enhance the capability for joining bows, sterns, and midsections on ships

Pier berthing should be equipped with flexible crane service and access, adjacent staging areas, and convenient access to fabrication and inside repair shops. A full range of pierside services would also provide power, high-pressure air, steam, fresh water, waste handling, fire mains and pumps, oily water removal and reprocessing, and environmental protection services.

Shop capabilities and facilities would include:

- pipe shop with pipe bending equipment
- steel fabrication shop with numerically controlled burning machines and with plate bending capability
- blasting and priming facility
- sheet metal shop
- electrical shop
- machine shop with CNC capability
- computer-aided design and manufacturing (CAD/CAM) capability

A full-service shipyard should also possess a range of specialized tools, jigs, fixtures, and test equipment. Selection of this equipment is based on the critical requirement to accomplish the project in a rapid turnaround environment. Examples of this type of tooling would include portable machine tools, mod-

ern welding machines and robotics, diesel repair support equipment, and test sets for sophisticated weapons systems when servicing naval warships.

A study published in 1993 by the World Bank found approximately 80 shipyards worldwide capable of handling the upgrade and conversion work on ships the size of high volume bulk carriers and larger.[4]

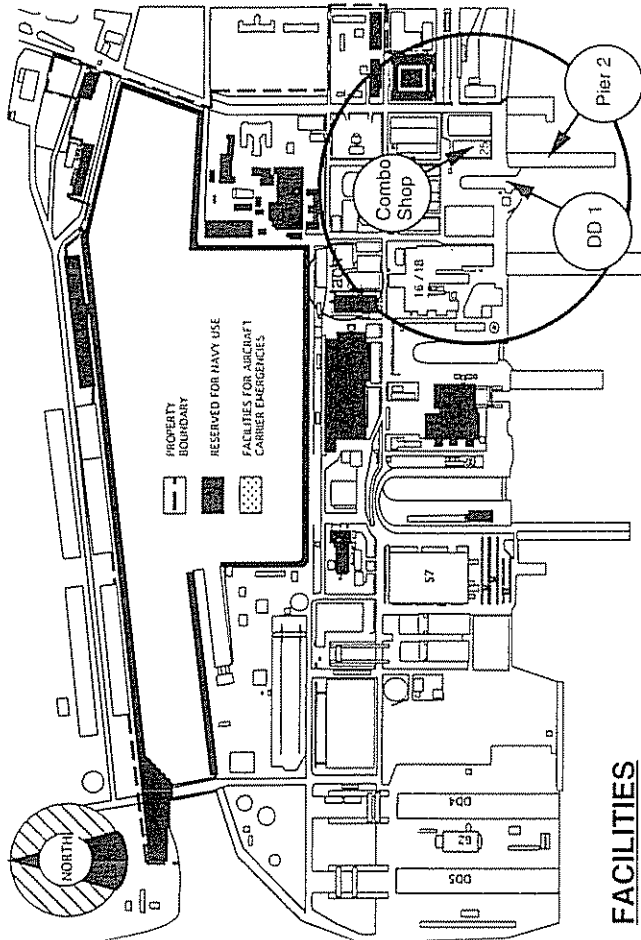
Smaller shipyards, especially those specializing in limited markets, may have only one dry dock, only small dry docks, only marine railways, only piers, or any combination of these. The combination of dry dock, pier, and shop facilities will be based on the market served and the capital investment that can be economically justified.

Various combinations of facilities were examined recently for possible ways to reuse the Philadelphia Naval Shipyard after it is closed by the government in 1996. Excerpts from this study showing representative layouts for a small repair yard and a larger repair/conversion shipyard are presented in Figures 9-6 and 9-7 to illustrate how these enterprises might be arranged.

So-called topside companies typically have only shop facilities, with no waterfront facilities at all. These companies have mobile teams with fleets of trucks equipped to do many types of repairs. They use sophisticated portable communication systems and specialize in rapid turnaround work on operating ships. Sometimes they have facilities at more than one port along a common shipping route, allowing them to provide coordinated service all along the route with equipment removal at one port and reinstallation at a subsequent port. They may participate in larger jobs by teaming with other shipyards or specialty subcontractors.

2.2. Planning Approach

Planning for conversion, overhaul, and repair has traditionally been based on ship systems. However, as zone technology has been in-



FACILITIES

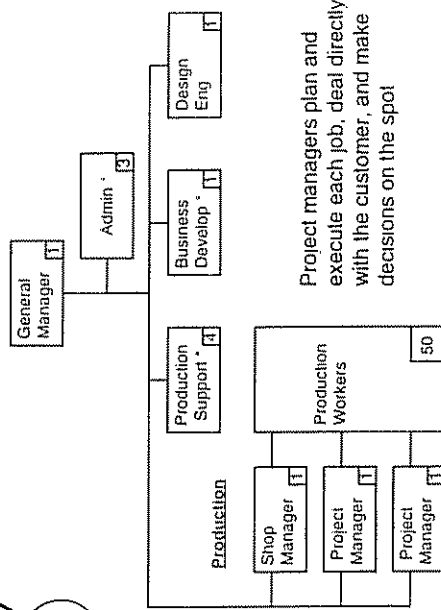
	Requirement	PNSY Facility	Size	Max Crane	Available
Piers	○	Pier No. 2	894 ft	60 T	1993 (RF)
Dry Docks	○	Dry Dock No.1	442 ft	60 T	1993
Shops:	●	Bldg 25-Rigging	53k sf		1995
Machine	①	(Use for all Functions in a Combined Shop)			
Pipe	①				
Electrical	①				
Fabrication	①				
Outfitting	①				
Sheet Metal	①				

SMALL REPAIR YARD

ORGANIZATION

- Executive 1
- Administrative* 3
- Business Development* 1
- Design/Engineering 1
- Production Support* 4
- Production Management 3
- Production 50

* Manpower requirements will be approximately double for military work.



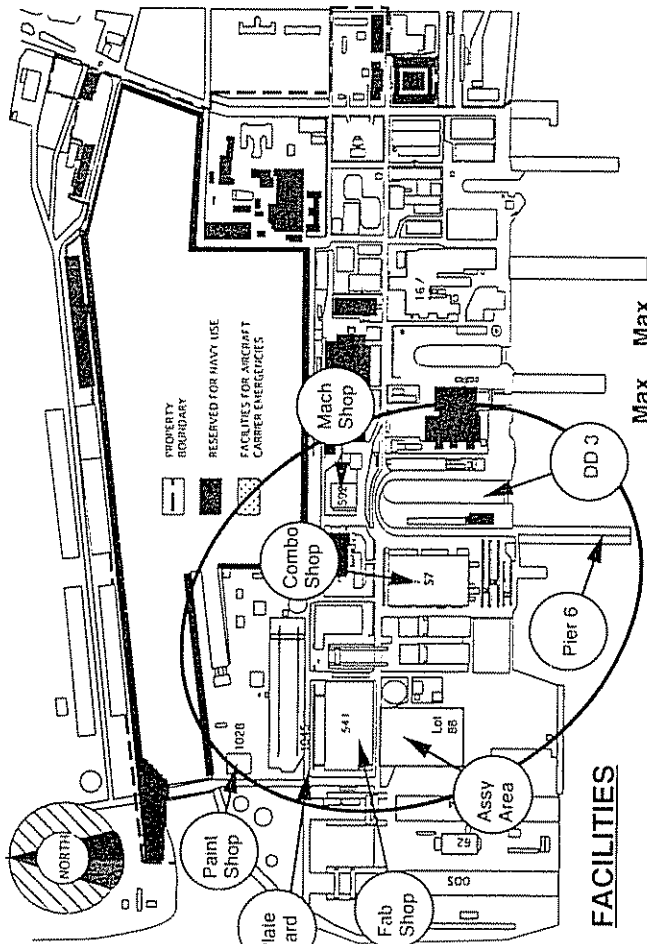
Project managers plan and execute each job, deal directly with the customer, and make decisions on the spot

Legend: ○ = Small ● = Medium ① = Combined shop functions RF = Tentatively obligated to Reserve fleet (NISMF)

Fig. 9-6. Representative layout for a small repair yard.

PHILADELPHIA NAVAL SHIPYARD

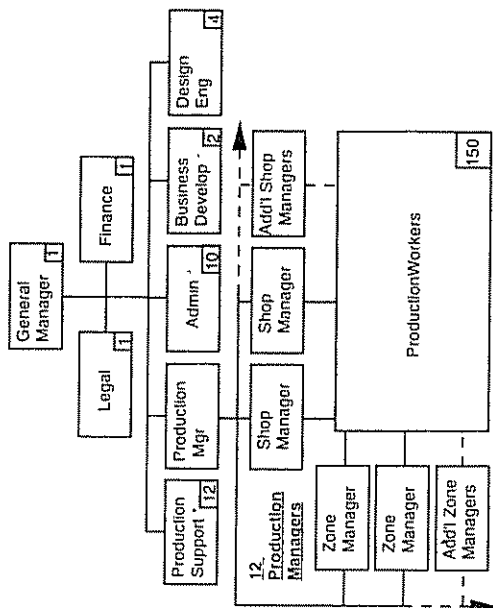
FACILITIES REUSE



ORGANIZATION

- Executive 3
- Administrative* 10
- Business Development* 2
- Design/Engineering 4
- Production Support* 12
- Production Management 12
- Production 150

* Manpower requirements will be approximately double for military work.



	Requirement	PNSY Facility	Max Size	Max Crane	Available
Piers	●	Pier 6	970 ft	50T	1996 (RF)
Dry Docks	●	Dry Dock 3	1011 ft	50T	1994
Shops: Machine	●	Bldg 592-Mach	81k sf	60T	1993
Pipe	●	Bldg 57-Combo	307k sf	60T	1996 (A/C)
Electrical	●	Bldg 57-Combo	307k sf	60T	1996 (A/C)
Fabrication	●	Bldg 541-Part	316k sf	60T	1995/96
Outfitting	●	Bldg 57-Combo	307k sf	60T	1996 (A/C)
Boiler	●	Bldg 57-Combo	307k sf	60T	1996 (A/C)
Sheet Metal	●	Bldg 57-Combo	307k sf	60T	1996 (A/C)
Plate Yard	●	Bldg 1045	68k sf	60T	1996
Assembly	●	Lot 88-Part	300k sf	Mobile	1994-Partial
Blast & Paint	●	Bldg 1028-B/P	13k sf	---	1995

Legend: ○ = Small ● = Medium ● = Large ① = Combined shop functions Tentatively obligated: RF = Reserve fleet (NISMF) A/C = Aircraft carrier emergency

Fig. 9-7. Representative layout for a larger repair/conversion shipyard.

creasingly implemented in ship construction, it has also been adapted for use in conversion, overhaul, and repair where it is justified by the size and complexity of the work. Within a zone approach, group technology (GT) with a product-oriented work breakdown structure (PWBS) focuses on developing repeatable work processes whenever possible, even when applied to considerably different ship designs.

2.2.1 Systems Approach. The traditional systems planning approach begins with initial identification of the repair requirements by systems. Operational logs are kept by system; component failure statistics are kept and evaluated by system; and in-service tests and inspections are done by system. Then cost and material estimating are done by systems, because that is the way the work is defined. Scheduling and authorization of production tasks are done by system and by trade. This works out neatly for the planners and schedulers because traditional shipyard trades are organized to work on systems of only one type (pipe, electrical, ventilation, etc.). Finally, testing is also accomplished by system.

The operation of the ship, maintenance and failure logs, design considerations, and testing are naturally and logically done by system. Planning for production work is done by system because the work scope has been defined that way in all the reports and supporting documentation. However, doing the production work by system makes sense only if it is sufficiently small and simple to be accomplished by a single person or small team without complicated interfaces to work on other systems.

When all the work is organized only by system and trade, the job of accommodating the interfaces between systems, planning resource utilization in tight spaces, and coordinating the use of bottleneck facilities, such as cranes, falls to the trade foremen. Individual

production trades wind up grouping and rescheduling tasks because work orders and procedures written on a system-by-system basis do not usually identify similar or adjacent/interface work.

However, no one person may have the overall picture of what work is to be done and when it is to be accomplished, especially on larger or more complex jobs. Trade and shop foremen may be forced to make resource and scheduling changes with no idea of the impact on other jobs and other trades. While trade supervisors may attempt to be objective, it is not unusual for work to be performed on a "first one in" basis, resulting in trade conflicts, rip-out of newly installed items, excessive rework, and wasted material. Experience gained by individual foremen may never be incorporated in future planning by higher-level management, or even by other craft foremen.

Scheduling by system is usually done in two stages. During the first stage, the basic elements—removal, inspection, repair (shipboard or shop), reinstallation, and test—are given approximate start and stop dates, and a few intermediate milestone dates are established. Preliminary information on scope and historical data are used to estimate total time-phased manning profiles and material requirements. In the second stage, more detailed project scheduling is accomplished, work packages are written, a critical path method (CPM) network may be constructed, and man loading is refined.

Networks drawn on a system-by-system basis generally result in a series of parallel lines which, in theory, are interconnected at each system interface. In practice, the interconnections tend to be insufficient to show real interdependencies. For small, time-constrained repair jobs, the tasks are, in fact, all done in parallel. The problems arise as the job gets larger and more complex, requiring a more sophisticated understanding and coordination of the task interrelationships.

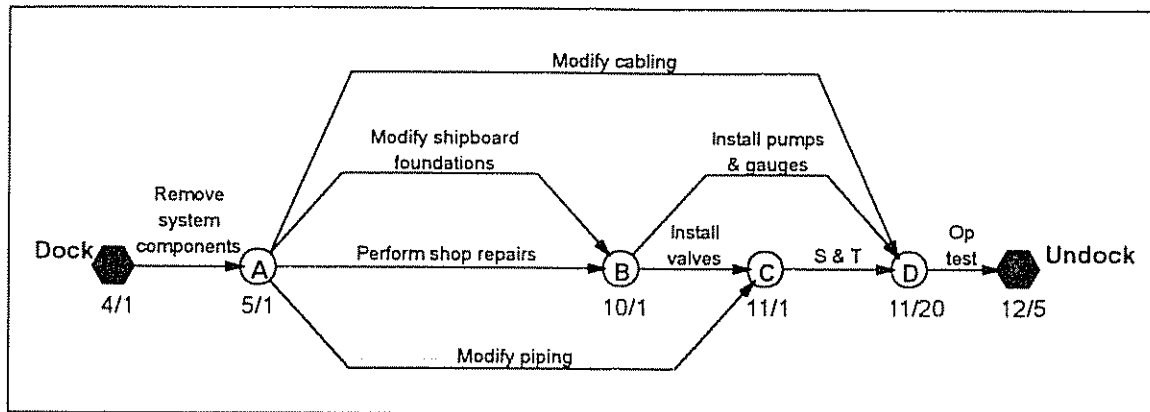


Fig. 9-8. Systems-oriented planning network for repair.

Figure 9-8 is a simple example of a network based on system. Components (valves and pumps) are to be removed and repaired, the pump foundations modified, electrical cabling ripped out and modified, and the system put back together and tested. Each of these operations is assigned a target time and resources for completion. The circles specify events or milestones that must be realized prior to proceeding to the next set of operations.

This network, based on one system, does not show interdependencies with work on other systems. The network could be expanded to include all work in a given space. However, the system overlaps into other spaces and a problem arises with the delineation of boundaries. Also, including all adjacent systems on the same network might make it too large and complicated to be a useful tool to the craft foremen. It would be difficult and expensive to maintain because of the rapidly changing understanding of the work scope. If it were not maintained it would become outdated and completely useless for the same reason.

If management insists on the use of inappropriate planning tools, this becomes a problem of the management system, and the tools will not be used. Rather, the trade foremen will generate their own ad hoc tools to do their jobs, but these will seldom be coordi-

nated with other trades for a project-wide perspective.

In the final analysis, these problems are not related solely to computer-based planning systems and CPM theory. The real problems are identification of resource requirements in terms of space and time, and delegation of authority to a management level cognizant of both of these elements.

2.2.2 Zone-Oriented Approach. Zone-oriented conversion, overhaul, and repair does not necessarily imply differences in the order or methods used to accomplish the work. In fact, zone orientation is intended to facilitate the planning, scheduling, executing, and testing of larger and more complex jobs in the manner in which they are actually performed across system and trade boundaries, in a manner consistent with concepts presented in Chapters II and III.

Creating zones is simply a convenient device for aggregating tasks in the most appropriate way for the tasks to be performed at any given stage of the job. Where the task is simple and confined to one system, a zone could be created for that system, meaning zone would equal system in that case. Where jobs are more complicated and work is focused in specific areas like the engine room, the auxiliary machinery space, or the bridge,

geographical areas might make more sense as zones within a particular phase of the entire job

A zone can be a compartment on the ship, only part of that compartment, a group of compartments, a system, part of a system, a group of systems, or a prefabricated unit being built in a shop. It can be any collection of tasks grouped logically for efficient performance. As with product-oriented new construction, sequencing is done in terms of problem areas and stages within a problem area. One component might even be part of different zones at various stages of the work.

The zone concept allows task grouping, resource allocation, and interdependency decisions to be made earlier and from a project-wide perspective, instead of in the heat of battle from the narrow perspective of a single waterfront foreman.

In general, the terminology of zone-oriented repair is the same as for zone-oriented construction. Problem areas and pallets, for instance, are defined exactly the same as for new construction. Zones are generally considered to fall into the following three categories:

- *geographic area*—discussed in Chapter 3
- *functional zone*—subdivision of the ship that includes all equipment associated with a particular system or component, such as all piping and pumps associated with a particular tank, as well as the tank itself
- *variable zone*—combination of functional zone and geographic zone that organizes the work by process, also known as a work zone

A stage is a substep or a band of time during an overhaul in which specific production processes take place. Examples include:

- pre-arrival planning, engineering, and scheduling (Pre-arrival preparation is being expanded by some owners and shipyards to include underway layout,

open and inspect, and rip-out wherever possible to reduce downtime for the ship during repairs.)

- prefabrication
- disassembly (rip-out)
- open and inspect (re-planning and engineering)
- repair or modification
- on-unit assembly
- on-block assembly
- on-board assembly
- testing
- trials

A typical work flow through these stages is illustrated in Figure 9-9.

In order to manage the work through each of these stages while doing the initial work definition, estimating, and early planning with a systems orientation, then changing to zones for production planning, scheduling, and execution (the way the work is actually performed), and changing back to systems for testing, it is necessary to be able to identify and describe each item that will be worked in a zone during one or more of the stages. A product-oriented work breakdown structure (PWBS) provides the ability to subdivide the repair/overhaul tasks in the manner in which they are actually conducted.

Figures 9-9 and 9-10 provide a guide for making PWBS decisions in an overhaul environment. They combine the ideas of timing (stage) with similar families of products (problem areas). Horizontal combinations shown in Figure 9-10 characterize the types of work packages needed for work to be performed at each level. This structure allows the work to be subdivided categorically by zone, problem area (specialty), and stage. Each category is then examined in relation to the other two. Using this technique it is possible to create a virtual flow lane for the required work.

A virtual flow lane may be thought of as an assembly line in which people flow by the work. The virtual flow lane optimizes use of

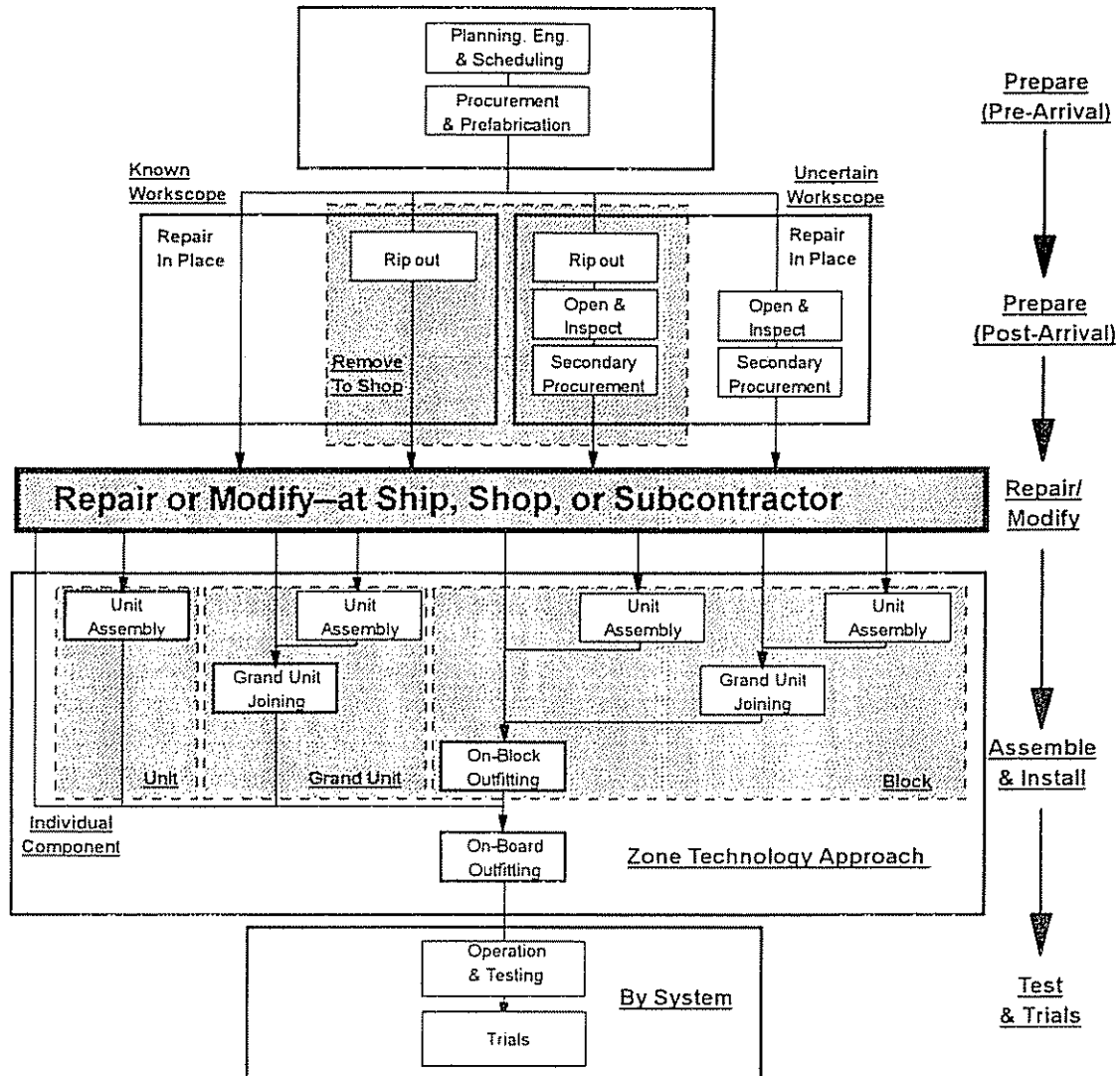


Fig. 9-9 Stages

production time by minimizing setup time between jobs of similar skill and by ensuring that the best possible environment exists when the cognizant trade arrives at the job site. This environment provides a safe workplace in which all needed materials are on hand and all interfacing work has been considered and properly sequenced.

Zone-oriented planning and scheduling is analogous to zone outfitting. Because of the large amount of information that must

be processed, an automated data processing (ADP) system is very helpful to realize the full benefit of the PWBS. CPM networks are not unlike those used by some yards for system-by-system overhaul. Essential differences are in the completeness and the boundaries of each network, the level of decision making, built-in feedback provisions, and the degree of coordination with material control. As with new construction, material control and the pallet concept are key elements. An addi-

PRODUCT ASPECTS									
ZONE	PROBLEM AREA					STAGE			
SHIP	DECK	ACCOM	MACH	NUCLEAR	ELEC	OPERATION & TEST			
ON-BOARD DIVISION	SIMILAR WORK IN SMALL VOL	SIMILAR WORK IN LARGE VOL	SIMILAR WORK IN LARGE VOL	SIMILAR WORK IN HIGH SKILL		REASSEMBLY			
BLOCK	COMPONENT IN LARGE QUANTITY	COMPONENT IN SMALL QUANTITY				REASSEMBLY			
GRAND UNIT	LARGE UNIT					WELDING			
						UNIT JOINING			
UNIT	LARGE SIZE UNIT			SMALL SIZE UNIT		WELDING			
						ASSEMBLY			
COMPONENTS	LARGE/SMALL QUANTITY	SPECIALTY	INTERFACES						
ON-BOARD DIVISION	BY SPECIALTY			ITEMS IN LARGE/SMALL QUANTITY		INSPECT/REPORT			
						DISASSEMBLY			
ON-BOARD DIVISION	BY SPECIALTY			ITEMS IN LARGE/SMALL QUANTITY		SORTING (DEPALLETIZING)			
						DISASSEMBLY			
COMPONENTS	IN-HOUSE MANUFAC	OUTSIDE MANUFAC	BUY	REQ FROM STOCK		PALLETIZING			
						MANUFACTURING			
						MAT'L REQ DEFINITION			
SHIP	DECK	ACCOM	MACH	NUCLEAR	ELEC	PREARRIVAL INSPECTION REPORT			
						SHIP ALTS			
						TECH WORK DOC			

Fig 9-10 Classification by product.

tional requirement is that the planning and scheduling system must consider those systems and subsystems that must be operational and on-line at each point in the overhaul.

2.2.3 Sample Planning Documents for Zone-Oriented Conversion and Overhaul. Figure 9-11(a) and (b) is an aggregate schedule, or overall plan, for one zone in a major conversion as performed at a naval shipyard. It provides the overall game plan for fabrication, outfitting, and installation of a modular system which is to be installed on the ship.

Figures 9-12 and 9-13 are examples of a package identification sheet and a corresponding composite drawing for the highlighted event in the aggregate schedule. Figure 9-12 lists operations from which the required resources are determined. The scheduled events are correlated to the work instruction documents used by the waterfront foreman (zone manager).

2.2.4 Product-Oriented Overhaul/Repair Example. Following is a simplified example which illustrates the concepts presented above. [1] Figure 9-14 shows a plan view of a hypothetical ship to be overhauled. The forward two-thirds of the ship represents a functional zone consisting of the firemain system in the forward portion of the ship. Figure 9-15 shows the first cut at geographic zoning which includes the port auxiliary machine room and one-half of the main machinery room. The variable zone, or work zone, is shown in Figure 9-16. This work zone has been determined by analyzing all work in the machinery space using the PWBS system. The following specific jobs are to be performed in the variable zone shown in Figure 9-16.

Job Orders

1. Replace 90" level grating.
2. Replace firemain piping FR 100102.
3. Replace demineralized water pump and motor.
4. Calibrate gauges system 1.
5. Calibrate gauges system 2.
6. Calibrate gauges system 3.
7. Add light frame 103-104 S/A 1000.
8. Renew pipe and valve main feed system FR 100-102.
9. Add vent duct S/A 2000.
10. Open/inspect/repair valves system 1.
11. Open/inspect/repair valves system 2.
12. Open/inspect/repair valves system 3.
13. Open/inspect/repair valves system 4.
14. Open/inspect/repair valves system 5.

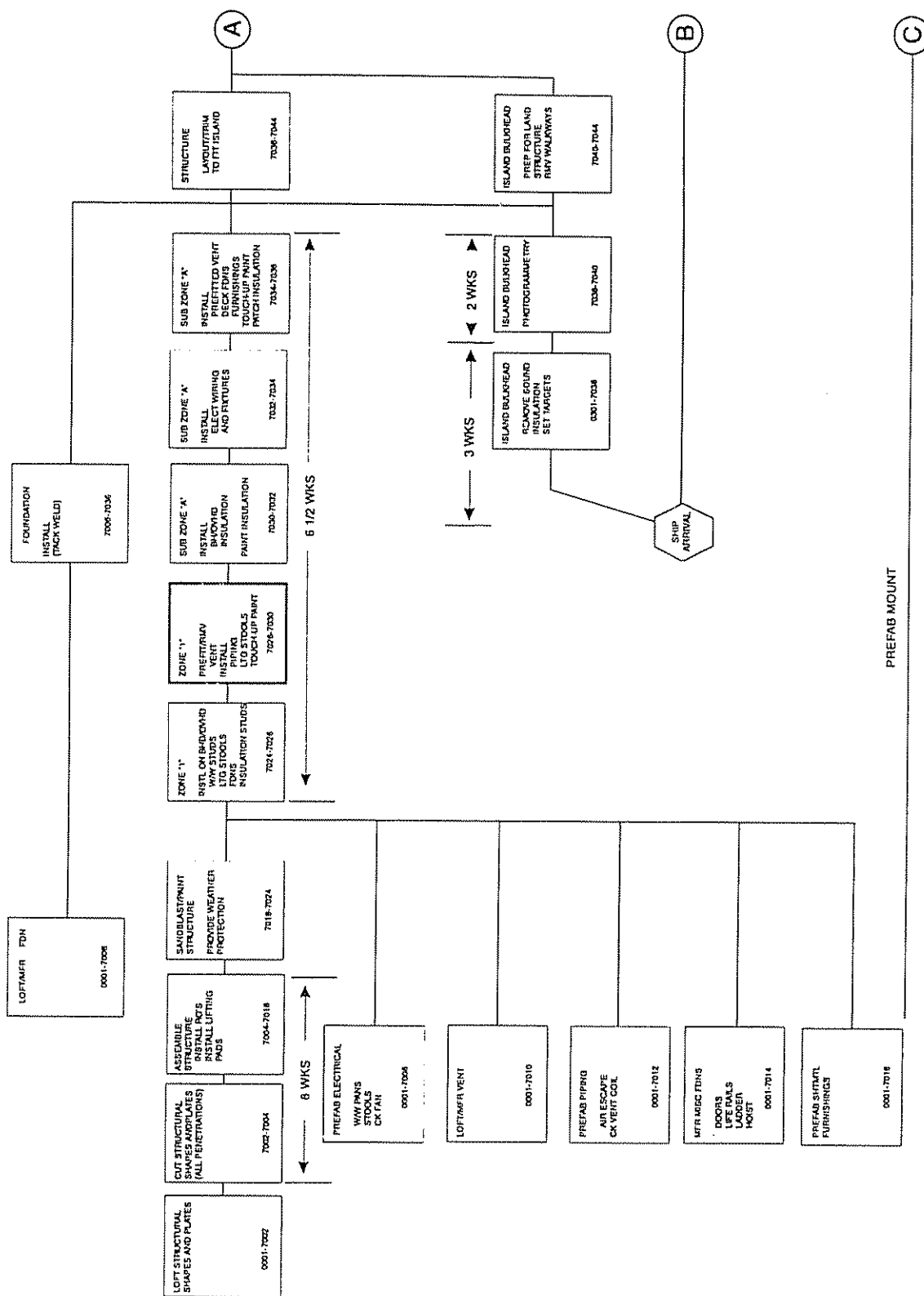


Fig. 9-11(a). Aggregate schedule for a zone-oriented conversion.

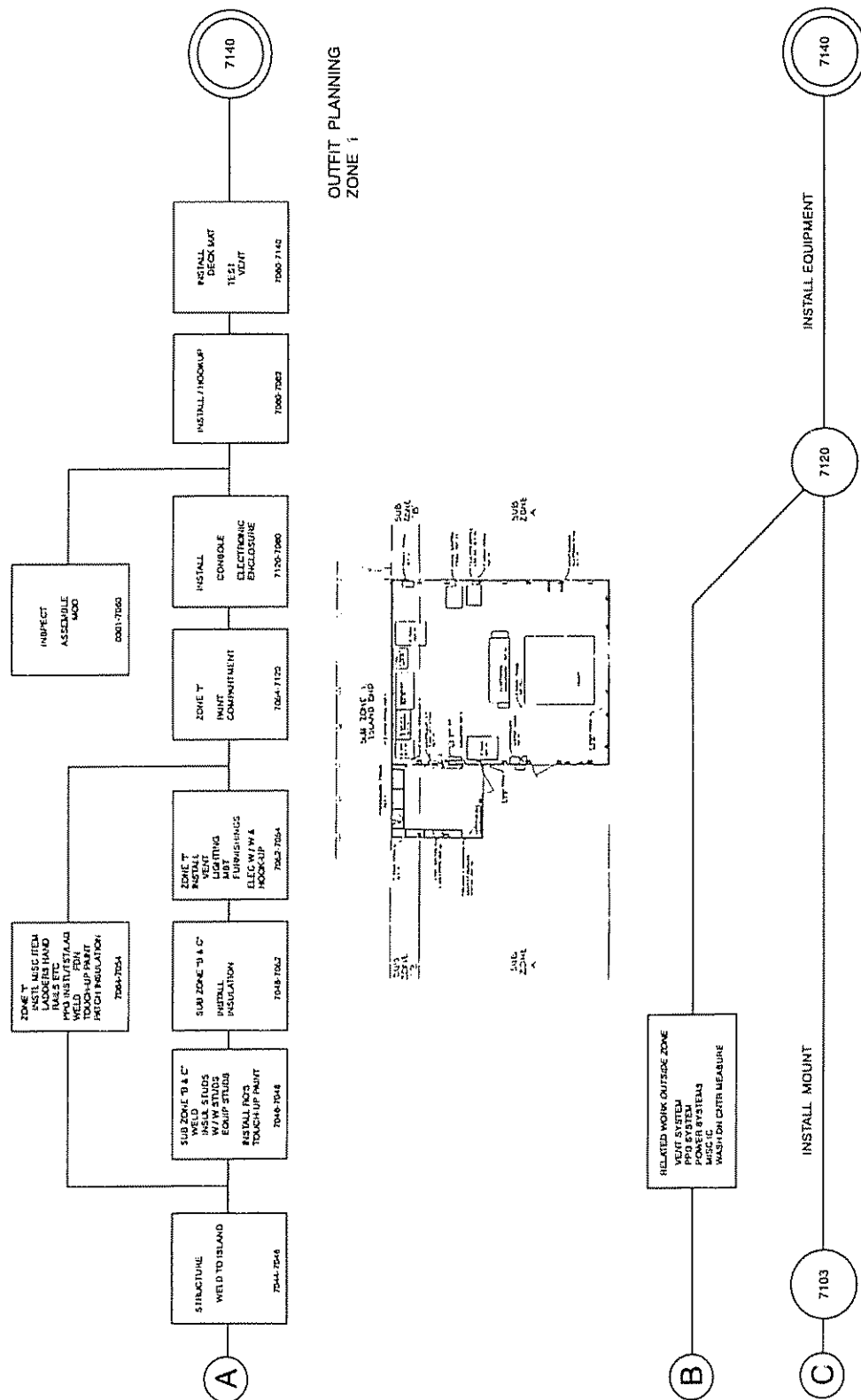


Fig. 9-11(b). Aggregate schedule for a zone-oriented conversion.

WORK PACKAGE 7026-7030

ZONE: "1" = 30

JOB ORDER: 20043-7004

(CIRCLE STAGE)

PREFAB/MFR SHOP PREFIT/OUTFIT SHOP TEST SHIP INSTL/OUTFIT SHIP TEST

WORK PACKAGE TITLE PREFIT/REMOVE VENT

KEY SHOP	KEY OP	REF	WORK DESCRIPTION	EST DURATION
017	069	14	PUR-FIT. INSTALL HANGERS AND REMOVE VENTS AS REQUIRED FOR INSULATION	
51	070	7	IN SUB ZONE "A" INSTALL LIGHTING STOCKS WHILE VENT IS IN PLACE	
56	068	15	PUR-FIT PIPING HANGERS (REMOVE AS REQUIRED IN SUB ZONE "E")	
56	068	16	PUR-FIT PIPING HANGERS (REMOVE AS REQUIRED IN SUB ZONE "B")	
56	068	17	PUR-FIT PIPING/HANGERS (REMOVE AS REQUIRED IN SUB ZONE "F")	
71	064	18	TOUCH UP PAINT AS REQUIRED	
17	059	14	PUR-FIT MOUNTING BRACKETS FOR GRAVITY TOLL - (REMOVE COLD FOR INSULATION)	
56	059	25	INSTALL AIR ESCAPE PIPING	
56	074	27	INSTALL L.P. AIR TO AIR HOIST	
			LONGEST DURATION	

LIST OF MATERIAL/EQUIPMENT/MACHINERY/FACILITIES

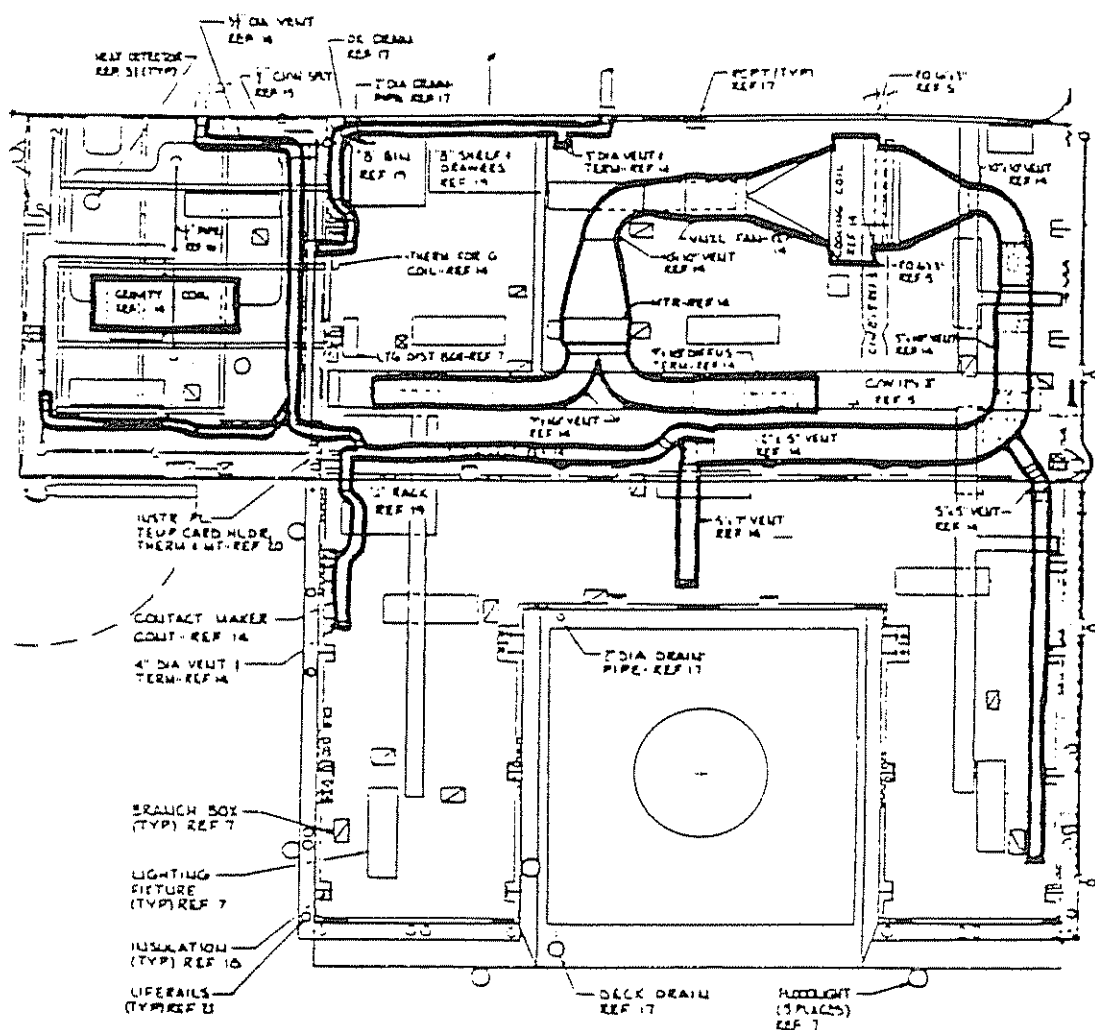
QTY

* VENT FAN & COOLER AND HEATER AVAILABLE

~~- IF NOT BUILD MOCK-UPS /USE FOR FITTING PURPOSES/~~

REMARKS

Fig. 9-12 Work package identification sheet



15. Add shock support and modify demineralized water pump foundation S/A 3000.

To accomplish the jobs listed above, the tasks shown below must be performed. These tasks have been organized by stage, including planning and engineering, procurement, opening and inspecting, secondary procurement, repair, on-unit assembly, and on-board assembly. This has been done by proceeding through the PWBS process as outlined in Figures 9-9 and 9-10. The resulting task breakdown of the overhaul, by stage, is shown below:

- Planning and engineering
 - Define jobs from customer.
 - Perform production planning
 - Write job orders or procedures
 - Define material.
 - Schedule work
- Procurement/fabrication
 - Procure material and fabricate demineralized water pump foundation.
 - Procure material and fabricate main feed system pipe.
 - Procure material and fabricate fire main system pipe
 - Procure material and fabricate vent duct.

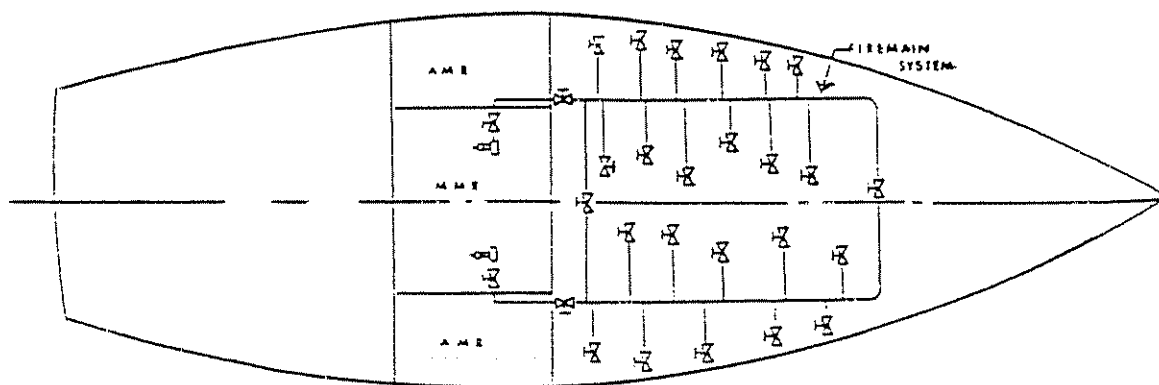


Fig 9-14. Hypothetical ship with functional zone

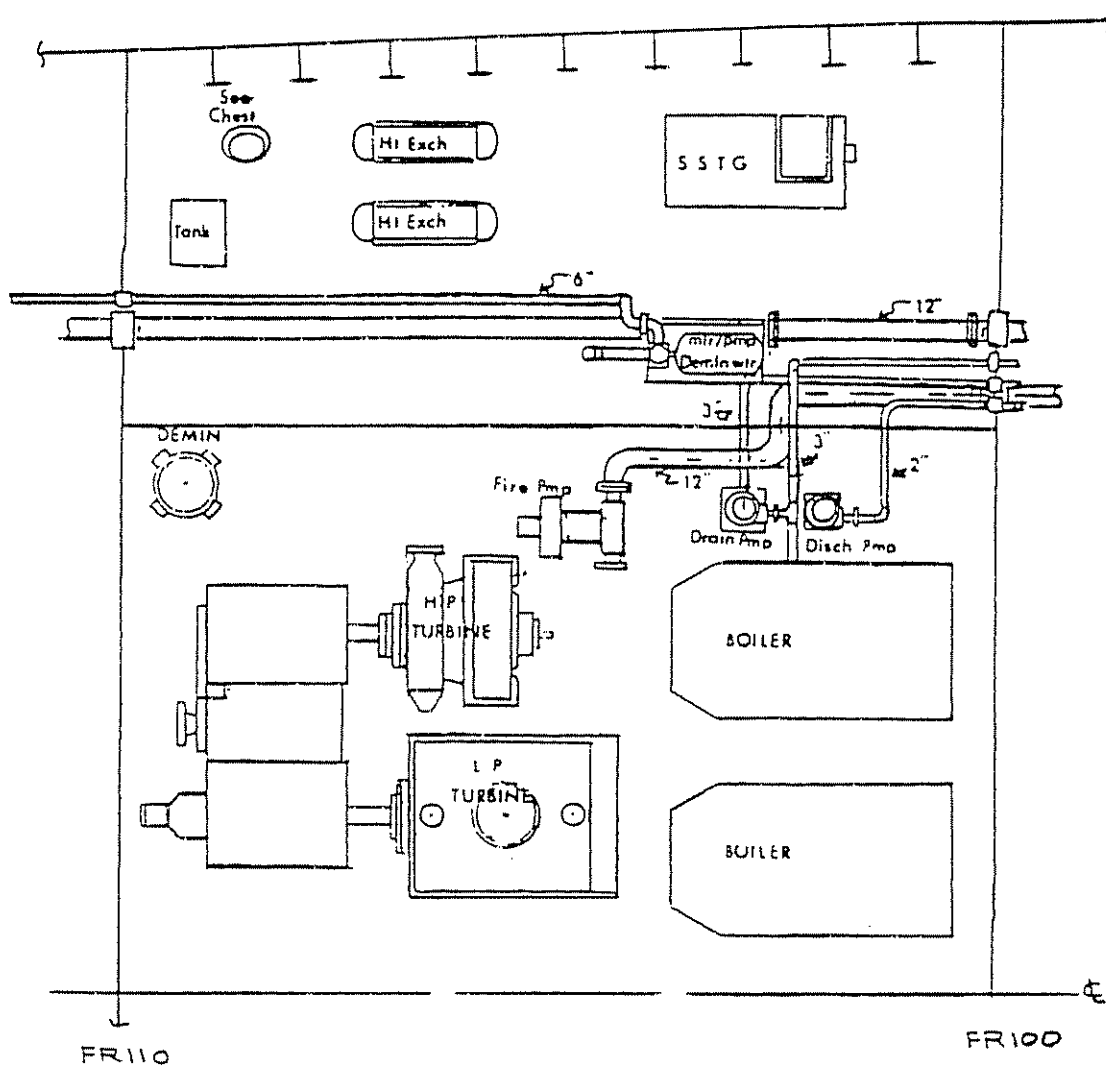


Fig 9-15 Geographic zone representation

- Procure material and fabricate light assembly
- Rip-out
 - Remove insulation.
 - Remove demineralized water pump and motor.
 - Remove main feed pipe assembly
 - Remove 9'0" level grating and demineralized water pump foundation.
 - Remove auxiliary saltwater piping
 - Remove fire main.
 - Remove gauges
 - Remove 6" demineralized water pipe, FR 100-103.
 - Install temporary staging, 9'0" level.
 - Cut temporary access
- Open and inspect
 - Open/inspect system 1, 2, 3 valves, flow path A.
 - Open/inspect system 1, 2, 3 valves, flow path B.
 - Open/inspect system 1, 2, 3 valves, flow path C
 - Open/inspect system 4 and 5, flow path B.
 - Open/inspect system 4 and 5, flow path C.
- Secondary procurement and repair
 - Procure material identified by opening and inspecting stage.
- Repair/alteration
 - Perform all repairs and alteration

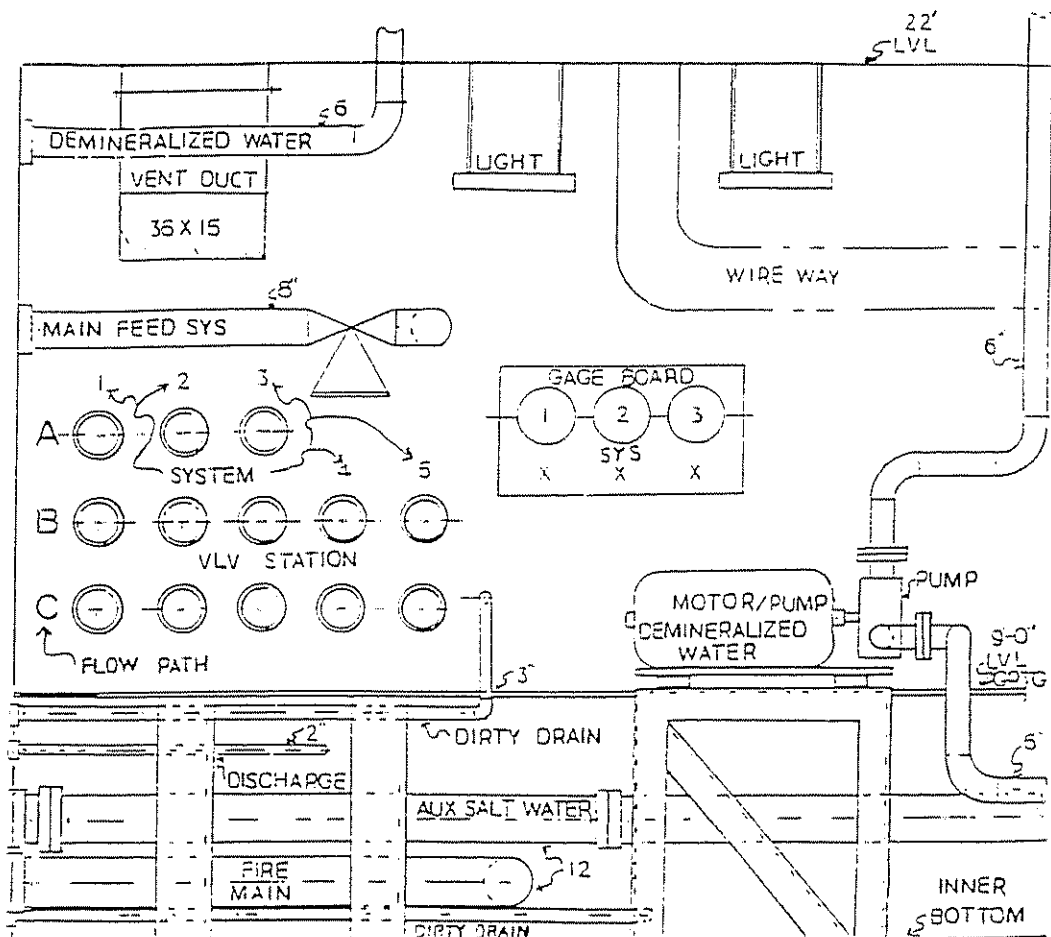


Fig 9-16 Variable zone representation

work aboard ship and off ship, such as valve lapping, component maintenance, etc

- On-unit
 - Assemble demineralized water pump unit.
- On-board
 - Reassemble system 1, 2, 3 valves, flow path A.
 - Reassemble system 1, 2, 3 valves, flow path B.
 - Reassemble system 1, 2, 3 valves, flow path C.
 - Reassemble system 4 and 5 valves, flow path B.
 - Reassemble system 4 and 5 valves, flow path C.
 - Reinstall system 1 gauge, flow path A.
 - Reinstall system 1 gauge, flow path B.
 - Reinstall system 1 gauge, flow path C.
 - Install vent duct.
 - Install main feed pipe assembly.
 - Install fire main piping assembly.
 - Reinstall auxiliary saltwater piping.
 - Install demineralized water pump unit and connect pipe.
 - Remove staging. Clean and paint bilge.
 - Install 9'0" level grating.
 - Close access cuts.
 - Install light.
 - Relag main feed and demineralized water piping above 9'0" level.
 - Clean and paint 9'0" level to 22' level.

Once the PWBS definition of the work to be accomplished by zone/problem area/stage has been completed, a schedule network for the tasks is generated. The schedule is then progressed, and, as work proceeds, tasks are rescheduled as necessary.

The application of group technology (PWBS) to major overhauls is underway in

both public and private shipyards. Many of the benefits realized in new construction are being observed in overhaul. These include reduction in delays caused by waiting for material, rip-out and reinstallation of recently performed work, and day-to-day competition for work space. The effects on morale, productivity, and cost are especially important in conversion, overhaul, and large repair jobs where work space is more restricted and the opportunity for physical separation of work tasks is limited. Task separation and reduction of interference is accomplished using PWBS by time-sequencing adjacent work. As with new construction, careful planning and scheduling, based on a comprehensive classification system, is essential.

2.2.5 Advanced Industrial Management A substantial effort is now ongoing in certain shipyards to further improve processes for identifying, planning, scheduling, and managing production work. This effort is a specific implementation of the concepts presented above in the product-oriented overhaul/repair example. The ultimate goal of this advanced industrial management (AIM) system is improved utilization of labor resources and increased productivity. The foundation of this work is an improved industrial language (work breakdown structure) for defining work. The program is sponsored by the Naval Sea Systems Command (NAVSEA).

The AIM language is a specific adaptation of PWBS and GT concepts to U.S. Navy shipyards and uses a component-based work breakdown structure that provides a standard set of rules, analogous to grammar rules, for any industrial activity. The basic grammar rules control how units of work are defined and organized (see Figure 9-17). Component units (CUs) are physical items that will have work applied to them, e.g., pieces of equipment on the ship. The CUs are analogous to "product" in PWBS. Criteria are established for identification of these CUs in order to

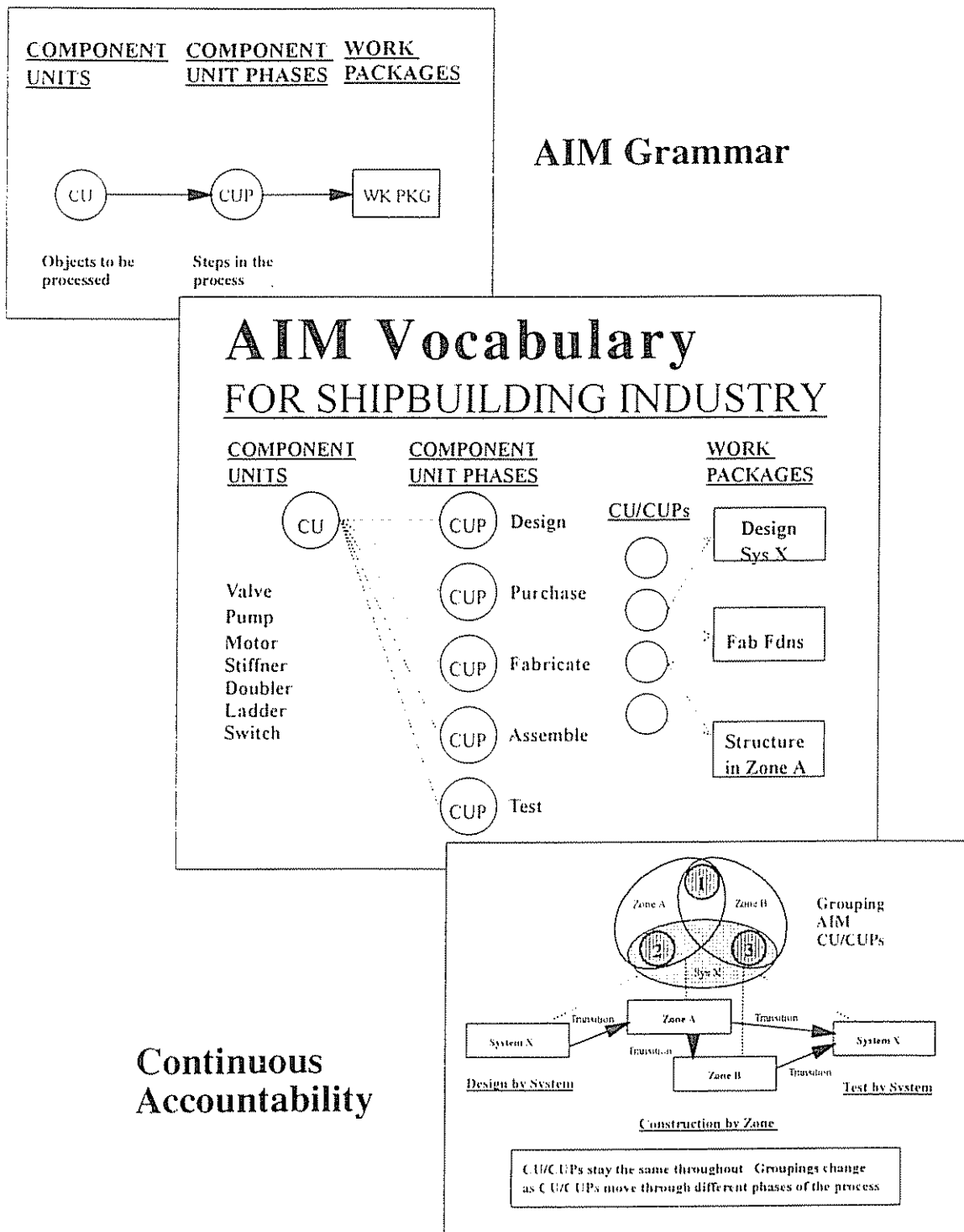


Fig 9-17 Using AIM

ensure that work is planned and managed at an appropriate level of detail. After CU criteria have been established, components can be identified by phases (analogous to stages), e.g., removal, repair, reinstall, test. [5] The CUs can be considered as objects or products to be processed, and component unit phases (CUPs) are steps in the process. CUPs can then be gathered into flexible work packages for effective execution or regrouped to meet changing work site conditions. Thus, the basic grammar rules define the relationships among CUs, CUPs, and work packages.

This grammar is used with a vocabulary of component units and phases developed for a particular industry (i.e. U.S. Navy shipyards). The CUs for ship repair include valves, pumps, motors, stiffeners, doublers, and many other items. Appropriate CUPs are established by analysis of the industry, and for ship repair, assembly, reinstallation, and testing, among others. Finally, the CUs and CUPs are grouped and regrouped like words in sentences and paragraphs by whatever criteria are appropriate for performing the work.

This system, with its standard grammar and vocabulary, provides continuous accountability throughout even the most complex process. As Figure 9-17 indicates, CU/CUPs stay the same throughout the entire process and can be readily tracked and monitored via a relational database, even though groupings of CU/CUPs change as the CUs move through different stages of the process. The AIM system can support any kind of simple-to-sophisticated project management approach and any type of work organization, whether by system or zone or both.

The AIM program attempts to apply a zone approach with a product-oriented work breakdown structure focused on the actual shipboard components (pumps, valves, etc.). The component-based work breakdown structure consists of a component unit (CU)

and standard phases of work (removal, repair, testing, etc.) called component unit phases. Since the components of a ship can be easily determined and standard phases readily established, this component-based work breakdown structure is particularly attractive for planning and packaging work. This work breakdown structure also lends itself to repeatability and reuse of planning products.

After establishing a component unit database that represents all the components on a ship, the AIM process specifies the creation of a job summary. The job summary is a strategic grouping of component units within a specific section of the customer-authorized work package. The job summary contains a brief description of the work on each component unit phase contained within the job summary boundary and estimates of both labor and material for each component unit phase. This document facilitates detailed planning on each component unit, allows early pricing of work and accurate bench marking of the estimate, and permits the repair activity to begin scheduling and packaging the work for effective execution very early in the planning process.

Detailed technical instructions are then written for each component unit phase described in the job summary. These detailed instructions are called task group instructions (TGI). Since they are written at a detailed level they make possible flexible work packaging and effective execution of work by zones using multitrade teams.

2.3. Management Approach

The traditional approach to ship repair management has been by function. This was because the work definition, design, estimating, purchasing, planning, and testing were all done by systems, the same systems that were the exclusive responsibility of specific trade skill functions. The pipefitters did pipe systems, the shipfitters built hull structure,

electricians ran wire and hooked up electrical equipment, machinists worked on machinery, and the sheet metal workers did ventilation.

This approach can be effective for smaller, simple jobs involving only a few systems. However, when the scope of work becomes too large, the work spaces too congested, or the work too complex or involving too many systems, this trade and system approach to managing a project frequently results in competition between different trades for work space and resources. The trades' primary concern becomes the success of their individual trades, not the health of the overall project.

For these larger, more complex situations, there is a need for an approach that allows a manager to step back and view the project as a whole and make decisions based on the overall good of the project, not a single trade. When this manager puts together a project management team with representatives from each of the major trades and support organizations, he or she has the tools for coordinating all the project work to meet the overall project goals. All shipyard shops and departments are expected to support the project team and to provide trained personnel and equipment as requested and funded by the project team.

The project team is structured to take advantage of the zone technology applied in the planning approach. Zone managers are identified and tasked with the proper planning and execution of all work within their assigned zones and they are responsible to the project manager for their daily performance.

Successful project teams clearly understand that their project is important in the business position of the shipyard. They establish a sense of urgency on the project; performance is expected; and the entire team either succeeds or fails. They establish clear metrics and routinely monitor progress and performance. They benchmark their performance against competitors. They staff the

project based on skill needs and value to the project. They establish and maintain a close working relationship with the customer.

Successful project management teams also exploit the benefits of group technology. The project team is responsible for all facets of the project and ensures that the key transitions from a systems orientation to a zone orientation are properly implemented and executed.

During the project planning phase, a key transition takes place that the project team's planning manager can facilitate. The systems orientation used during basic design and planning is transformed to a zone orientation. This transition is improved if the zone managers are part of the project team. They can work closely with the project planning manager and determine project strategy, establish zone boundaries and groupings, and initiate discussions on effective work packaging within the various zones. The project team approach greatly facilitates the planning of integrated work flows by promoting discussion, tradeoff, and mutual consent between the project team members.

Another key transition, back to systems orientation, occurs late in the life of the project. This happens when a systems orientation is required to allow system testing, product certification, and overall project evaluation. Once again this transition is facilitated and more effectively executed if the test personnel, certification personnel, and other associated parties are members of the integrated project team. If they have worked closely with the project planning manager, zone managers, and the team's production personnel during the life of the project, then this transition and the success of the project is enhanced.

The project team approach can also facilitate the introduction of a more participative approach to the planning and execution of a project. It firmly establishes team ownership for the planning, execution, and overall customer satisfaction of the final product. Fi-

nancial results and accountability are also clearly established at the project (revenue center) level. All of these factors have been shown to be key ingredients in the success of a high-performance work team. [6]

Representative management structures for a small repair yard and a larger repair/conversion shipyard are presented in Figures 9-6 and 9-7 from the Philadelphia Naval Shipyard Reuse Study presented in Section 2.1. of this chapter. In the small shipyard, project managers plan and execute each job, deal directly with the customer, and make decisions regarding the project themselves. In the larger ship repair/conversion shipyard, a

matrix management organization comprises both zone and shop management for the production work, a production manager responsible for production decisions, and additional administrative/business development positions to assist with customer interfaces.

Each of the following sections will discuss the requirements for jobs of different size and complexity and how to select an appropriate planning and management approach:

- repair and overhaul
- conversion and modernization
- deactivation
- scrapping

3. Repair and Overhaul

A ship needs to be operating to earn money for its owner or, if it is a military ship, to perform its mission. In order to maximize operating time during its service life, a ship must be repaired when damaged and maintained regularly to avoid breakdown and deterioration.

Classification societies publish rules for maintenance of the vessels they classify. Surveys are conducted at intervals, with the type of inspection varying with the age of the ship. In addition to regular surveys, the societies require that damage repairs be accomplished according to society rules.

In addition to classification society inspection, government agencies inspect merchant vessels to assure that they are maintained according to published rules. In the United States, merchant vessel safety inspection is carried out by the U.S. Coast Guard. (Classification societies and regulatory bodies usually coordinate their efforts to eliminate overlapping requirements and redundant inspection cost. This is sometimes formalized through documents of agreement.)

Repair and maintenance of ships generally falls into three categories discussed below:

- unscheduled voyage repairs
- planned maintenance
- overhauls

3.1. Unscheduled Voyage Repairs

The need for unscheduled voyage repairs results from damage or breakdown occurring during operations. Damage can come from exposure to heavy seas and weather, collisions, groundings, fire, explosions, or flooding. Breakdowns and other equipment failures can occur at any time. Whenever one of these events does occur and the ship must be repaired, it is an emergency, affecting the ability of the ship to operate safely and perform its mission. Emergency repairs require immediate attention; otherwise they would be postponed until a more convenient time, preferably the next planned maintenance period when the work could be bid as part of a larger work package to keep the cost down.

Even when there is competition, emergency repairs tend to cost substantially more than routine maintenance. This is because the emphasis is on placing the ship back in service as quickly as possible. The cost of the ship being out of service is generally much more than the cost of the repairs. Therefore,

there is an economic incentive to find ways to minimize out-of-service time or even accomplish repairs with riding crews to avoid it altogether.

The size and complexity of unscheduled voyage repairs can range from very small and simple, such as replacing the bearings in an important pump, to very large and complex, such as collision damage resulting in an extensive engine room fire. This means that the range of approaches that can be taken to the repairs can vary just as widely. Four examples showing this range are presented in Figure 9-18 (plotted on the approach selection graph presented earlier as Figure 9-5) and are discussed below.

3 1 1 Case 1. Ships frequently encounter lost fishnet, some that are miles long, invisible, and floating just below the surface. Having a propeller fouled by a fishnet is a small-scale problem that is simple to remedy, but important for continuing operations. It obviously falls below the threshold for a sophisticated planning and management approach.

- **Facilities**—This repair requires no special facilities. It can be done by a diver at the pier where the ship is berthed. Alternatively, the ship can be reballasted to bring the propeller out of the water and a small team in a boat can cut the net free.

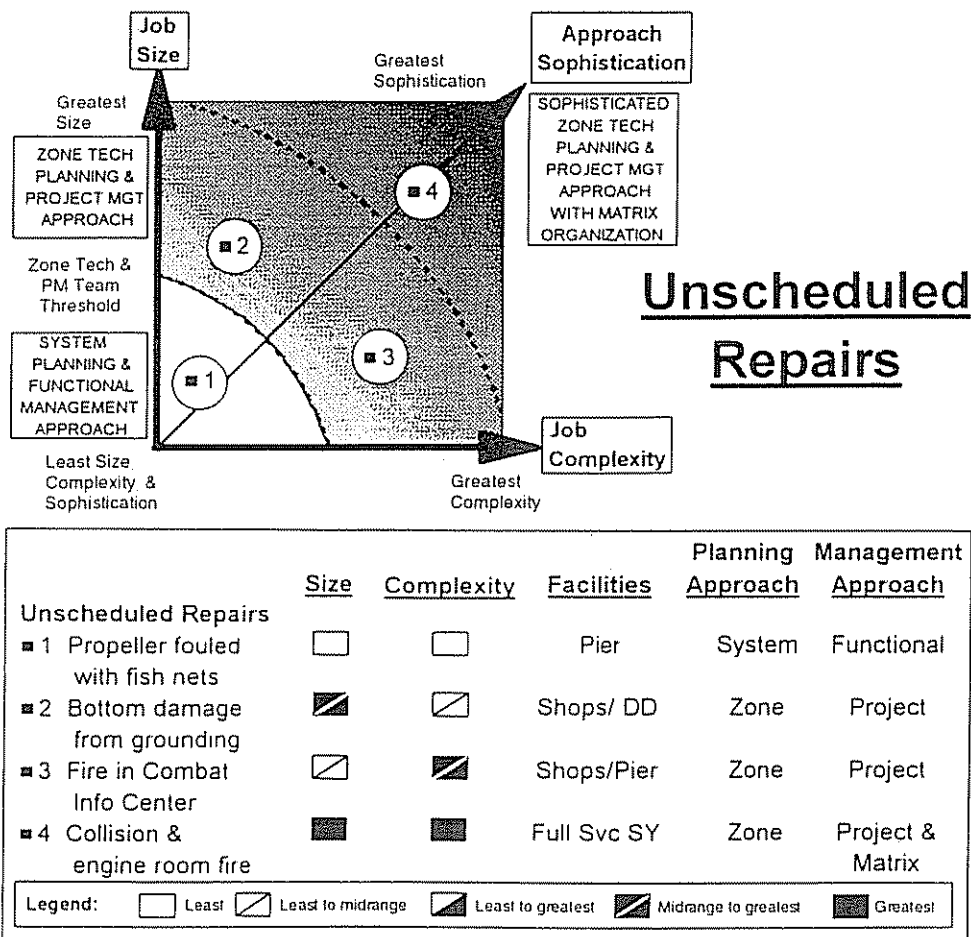


Fig 9-18. Unscheduled voyage repairs

- *System planning approach*—There is only one system involved and the planning can be done on-site by the team leader.
- *Functional management approach*—One responsible team leader can take full responsibility for everything from renting a boat, bringing in helpers and tools from the shop, and planning the work, to handling the paperwork with the ship's master or agent.

3 1.2. *Case 2* Bottom damage from grounding on a sandbar or some other obstacle is also a common emergency repair. It can be large in scale but is not usually technologically complex. Though unusual today, damage on an old ship may be more complex if rivet strakes are damaged, because there is little

capability for rivet technology remaining in the industry today. Any hull damage also becomes more complicated if the damage extends to the internal structure or systems, especially if it involves piping, electrical, sonar, or other systems. Finally, this is a classic example of being uncertain of the work scope until the ship is examined out of the water. Sometimes a diver is used to examine the damage first, but much of the damage may be to structure inside inaccessible tanks. Because of the size of a bottom damage job and its requirement for a dry dock, it would lie above the sophisticated approach threshold. Two examples of bottom damage are illustrated in Figures 9-19(a-d) and 9-20 (a-d). The first shows the crumpled bottom shell plating and internal structure being removed, replaced with new parts and assem-

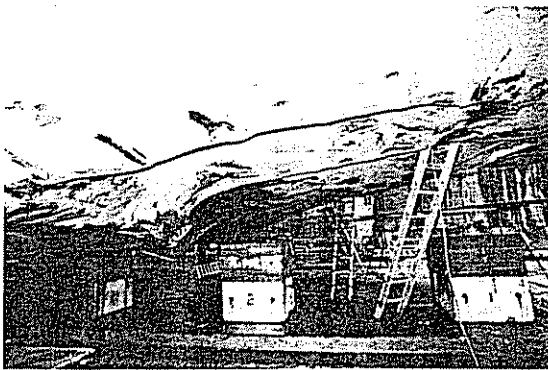


Fig 9-19(a)



Fig 9-19(b)

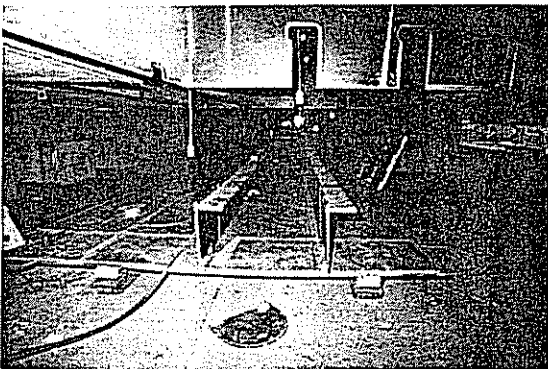


Fig 9-19(c)

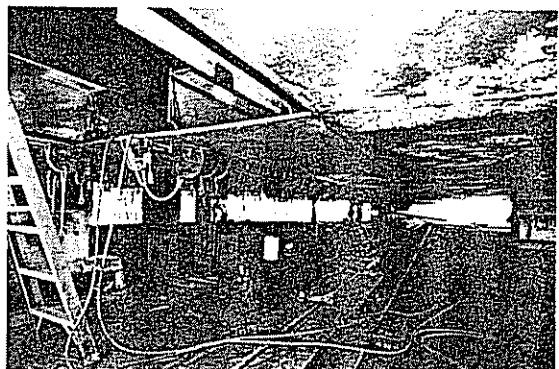


Fig 9-19(d)

Fig 9-19 Example of bottom damage.

blies, and fitted for final welding. In the second, the bow forefoot has been so severely damaged that an entire lower bow assembly has been constructed to shorten the repair cycle. The fully painted assembly is positioned in the dry dock using both cranes and

track-mounted positioners capable of rolling and lifting the assembly into final position for fitting and welding.

- *Facilities*—The big requirement is for a dry dock. Since this is an emergency

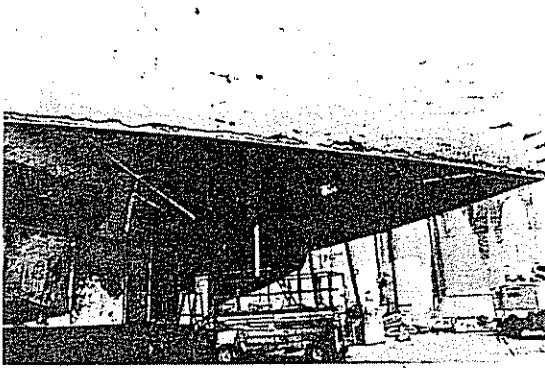


Fig 9-20(a)

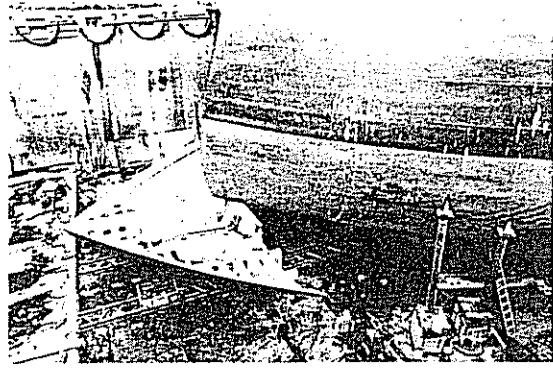


Fig 9-20(c)

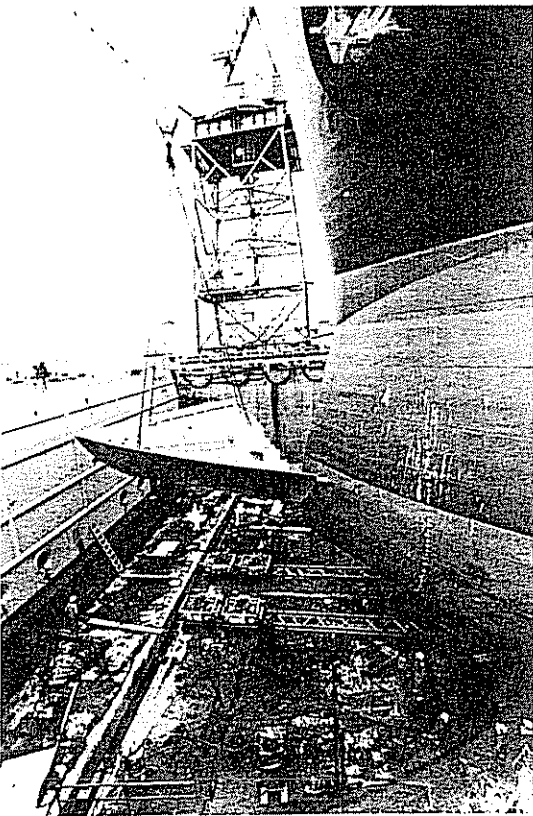


Fig 9-20(b)



Fig 9-20(d)

Fig 9-20. Example of bottom damage

repair, and dry docks are frequently booked up, it may be difficult and expensive to dry-dock the ship, especially if the ship is not allowed to transit to a dry dock in another area before the repair is complete. Other requirements involve steel-handling, fabrication, and welding facilities. A crane and other material-handling equipment will be needed, as well as blasting and painting equipment. This job should be done at a shipyard.

- *Zone planning approach*—The damage may extend over a large enough area that it should be broken down into several geographical zones fore and aft or port and starboard. The work might be divided between inside and outside zones. A zone might be created for any structural units that could be prefabricated. The zones should reflect the most effective way to do the work.
- *Project management approach*—This job may involve a substantial number of workers, but they will come from only a few trades (shipfitters, welders, tank testers, painters) and support people for material handling and operating the dry dock. The project team will need to order steel; coordinate with the insurer, classification society, and Coast Guard for inspections; and arrange for the shops to make up prefabricated units. The team may also have to arrange to accomplish a lot of growth work because placing a ship on the dry dock is expensive and shipowners like to take advantage of the opportunity to have nonemergency underwater work and pending surveys done without paying for a second dry-docking or taking the ship out of service again.

3.1.3 Case 3 Fire in a combat information center of a military ship is less likely to be encountered. It is, however, an example of

damage that might not be great in size, but be very complex and affect many systems on the ship.

- *Facilities*—This work can be done at pierside. It does not have to be a shipyard pier, but it would be preferable to have the ship near the shops, shipyard crane, and other material-handling services. An electronics shop will be needed, though some of this work may be subcontracted. There will be some structural work requiring steel and perhaps aluminum fabrication and welding facilities. The ventilation, pipe, electrical, and joinery shops will also have tasks to do.
- *Zone planning approach*—While the fire may have been confined to one space, it damaged the controls, monitors, and wiring for systems that go all over the ship, as well as the many support systems serving that space. It might make sense to divide the burned-out space into zones that would change by stage. One set of zones might make sense for rip-out, another for structural repairs, and yet another for equipment installation and wiring. Since much wiring is sure to be damaged and some types of wiring are not allowed to be spliced, there may be a requirement to rerun electrical cables to many places throughout the ship which could also be one or more zones. Finally, a system approach is used for the massive test and certification program.
- *Project management approach*—The job will involve many trades, the services of original equipment manufacturers, in-house electronics experts (or, more likely, subcontractors), certification agencies, and an intricate, extensive test program. It will be necessary to coordinate the many people from different trades and companies, all

working in the confined space, to ensure that they can get their jobs done effectively without compromising the goals of the overall project. Creative approaches may have to be used to get long-lead-time material more rapidly than usual. This definitely calls for a sophisticated project team, but not necessarily a large one

3 1 4. *Case 4.* The last case is the most extreme one. Before repairing a ship that was in a serious collision and suffered a major engine room fire, the owner would have to consult with the insurer to determine whether it makes economic sense or whether the ship should be scrapped. Damage in this scenario could take a year or more to repair and include gutting the engine room, re-engining the ship, replacing support systems, installing new switchboards and wiring, renewing much of the structure, and probably performing other work throughout the ship. An owner might take advantage of this situation to modernize the ship or even convert it, if the market and economic conditions called for it. The extent of this type of unscheduled repair is most analogous to conversion and modernization

- *Facilities*—This work requires a full-service shipyard, including a dry dock.
- *Zone planning approach*—A project of this size and complexity needs the same type of sophisticated zone approach used for conversion and modernization. The main differences would be the additional zone structure set up for the extensive removals and the greater amount of work scope that remains unknown until the removals are made and an in-depth survey is completed.
- *Zone management approach*—A job of this nature requires the most sophisticated project management team working with a large shipyard work force

in a matrix relationship. The project team should include members from all the major shipyard organizations to coordinate planning, material ordering, prefabrication, production, subcontractors, testing, and contract management

3.2. Planned Maintenance

By definition, planned maintenance is not emergency in nature. It is based on mandated surveys by the classification societies and regulatory agencies, inspection logs and performance records of the operator, and a regular maintenance program run by the owner based on his or her own maintenance philosophy, statistical information on equipment failure rates, or predictive data collection. All these programs are designed to keep ships operating safely with a minimum of downtime.

The size and complexity of a planned maintenance can range from very small and simple, such as servicing idle equipment while underway, to moderate, such as a more extensive periodic survey on the dry dock. This means that appropriate planning and management approaches will vary from simple to moderate in sophistication. Three examples showing this range are presented in Figure 9-21, plotted on an approach selection graph and are discussed below.

3 2.1. *Case 1.* In the past when crew sizes were larger, a substantial routine maintenance program could be accomplished while the ship was underway. Today's smaller crews are not able to perform as much maintenance and still have time to operate the ship safely. Underway maintenance is often done now by special riding teams (in-house or contractor) or a temporarily expanded crew. This type of maintenance is usually preventative type maintenance and routine repairs on individual pieces of equipment. It is small in scale, simple in scope, and falls below the sophis-

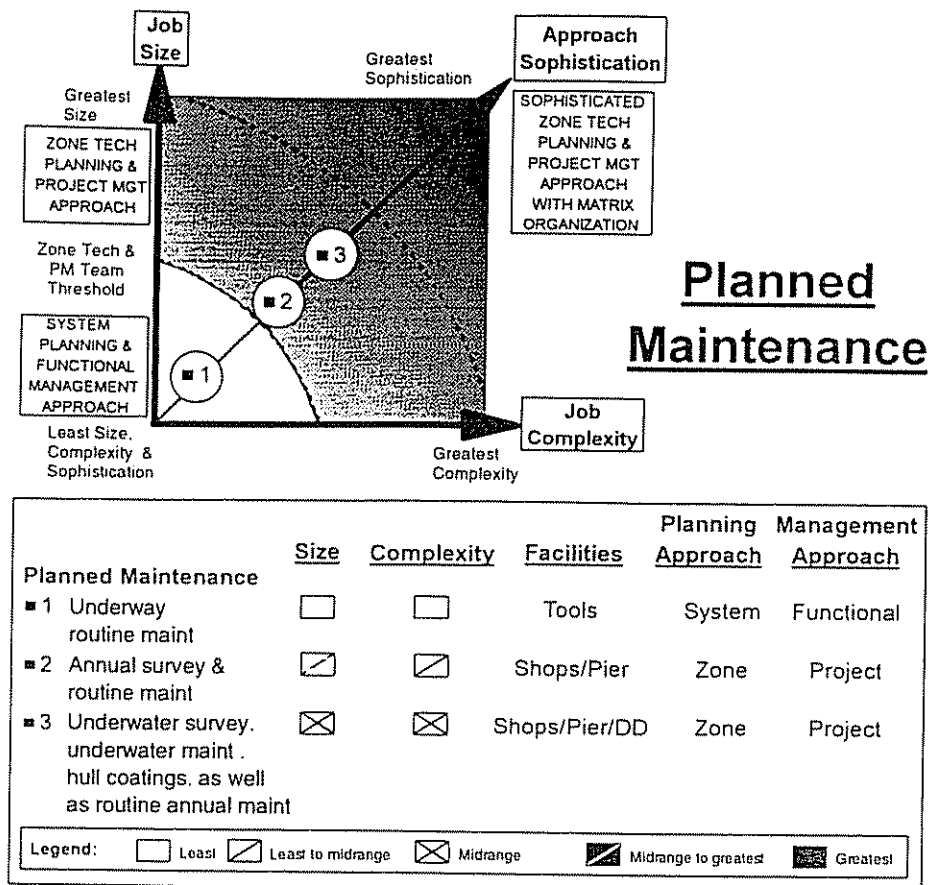


Fig 9-21. Planned maintenance.

ticated approach threshold. What may be sophisticated, however, is the philosophy, engineering, and strategy behind the maintenance program.

- **Facilities**—Some tools and equipment are carried aboard ships, but most work teams will bring their tools with them.
- **System planning approach**—This type of equipment maintenance program is usually designed around individual systems and components.
- **Functional management approach**—Usually only a few trade skills are required, such as machinists, pipe fitters, and electricians. One responsible team

leader can take full responsibility for all aspects of performance to the plan.

3.2.2. Case 2. In order to maintain their initial classifications, steel ships are usually surveyed annually. At pierside, the condition of hull closure appliances, freeboard marks, and auxiliary steering gear is inspected by a representative of the classification society. Concerned with safety, regulatory bodies check out stability, fire protection, machinery and electrical system safety, hazardous and polluting substance control, lifesaving equipment, and navigation and communication equipment. Planned maintenance and repairs are accomplished, usually under a contract with a shipyard or topside repair company, and may

last from a week for some commercial ships to several months for a military ship. Sometimes preparation for the in-port planned maintenance is done at sea with a riding team to reduce the required time in port. This is done frequently on cruise ships because of the high cost of having them out of service.

- *Facilities*—This work can be done at any pier, but is more convenient in a shipyard with access to cranes, shops, and controlled staging areas. Otherwise, workers, tools, and material have to be transported to and from the job site daily.
- *Zone planning approach*—Work is done throughout the ship and is best coordinated using zone technology, since there is time for a well-thought-out approach.
- *Project management approach*—A small project team can handle most jobs of this magnitude, especially since the members can participate in the early planning.

3.2.3. *Case 3.* At larger intervals (up to five years) the classification societies require that ships be inspected in dry dock for corrosion, chafing, or distortion of the shell plating; stern frame and bearing wear; or shaft, propeller, and rudder damage. The requirements of an annual survey are usually also accomplished at the same time, along with nonemergency repairs that have accumulated since the last maintenance period and other work required by the owner's maintenance program. This may include opening, inspection, and repair of main machinery including engines and gears. Figure 9-22 shows the rigging needed to remove a bull gear from the main reduction gear during a repair cycle. Additionally, the hull is blasted and painted with both anticorrosive and anti-fouling coatings. The cathodic protection system is checked out and zinc anodes replaced.

The freeboard marks, load lines, and draft marks are checked and painted. A docking planned maintenance may last as little as 10 days for some commercial ships or as long as 6 months for a military ship and include ship alterations. As in Case 2, underway preparation may be done prior to ship arrival to minimize time in port.

- *Facilities*—Most often the work is done by a shipyard with a dry dock. In some ports a topside company can dock the ship in a publicly owned dry dock to perform the job or team with a shipyard that has a dry dock. In some Navy home ports the Navy has a dry dock it makes available to small businesses. Other facility requirements include piers, shops, and cranes. It is not unusual for there to be damage to the propeller, shafts, or rudder that requires the use of oversized lathes and other special equipment. This is subcontracted if the shipyard does not have sufficient machining capabilities.

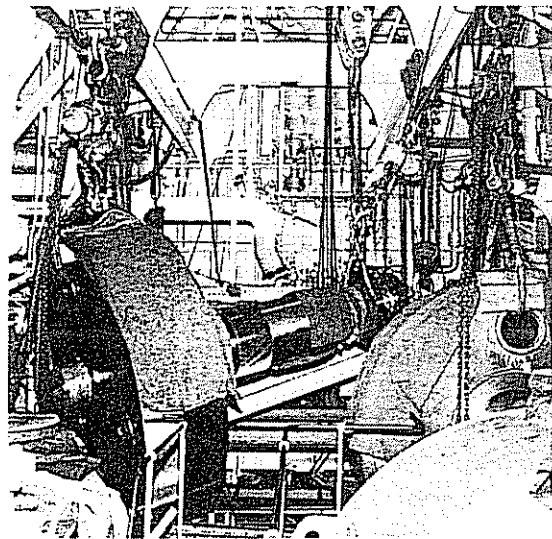


Fig 9-22 Rigging needed to remove a bull gear from the main reduction gear during a repair cycle.

- *Zone planning approach*—As in Case 2, there is work throughout the ship, and there is time to adequately plan the zones. Work identification should be thorough, but there will also be some work that cannot be known until the machinery, equipment, and tanks are opened and inspected.
- *Management approach*—This work requires a larger project team than Case 2. This is due in part to the increased size of the work scope, but more importantly to the required coordination of the dry dock work with the other work on the ship. For example, hull blasting and coating interfere with almost every other activity on the ship, especially “hot work” (welding or burning) which can cause the volatiles in paint to burn or explode. Most of the individual tasks are relatively straightforward, but since virtually everything must be done in parallel to minimize both time out of service and time in the dry dock, careful project coordination is necessary for effective and safe operations.

3.3. Overhaul

Overhaul is a special larger-scale type of planned maintenance. Its purpose is to bring the overall operating condition of a ship back to good-as-new, as well as to perform all the work in Section 3.3.2. While major ship alterations may be performed (such as adding new weapons systems to a Navy combatant), overhaul is usually concerned with making the same systems work like new, not replacing them with more modern ones. However, overhaul is similar in many respects to conversion and modernization (discussed in the next section), especially in the planning and management approach.

Overhaul is a large and complex undertaking, lasting from a few months to a year

for many military ships. Appropriate planning and management approaches always involve zone planning and a project team. Three examples are presented in Figure 9-23, plotted on an approach selection graph, and are discussed below.

3.3.1 Case 1. Overhaul of small craft, such as tugs and other workboats, still involves virtually all the systems on the boat, even though the boat and the equipment are both smaller and simpler.

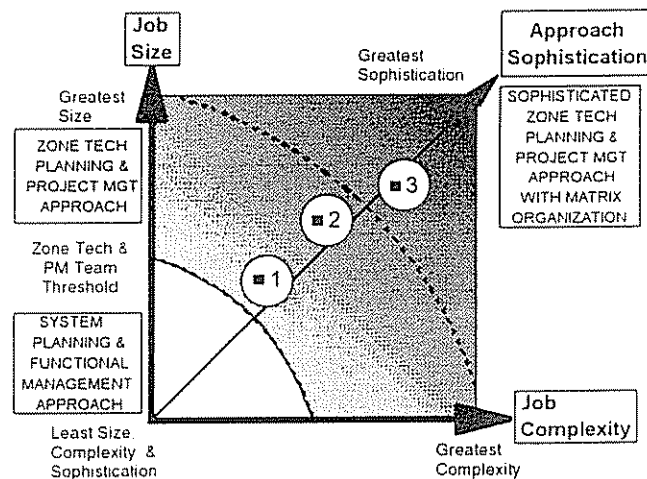
- *Facilities*—The boat will need to be removed from the water for hull and propulsion/rudder work. This may be done with a small dry dock (where more than one boat may be docked at a time) or on a marine railway where the boat is pulled out of the water; in some cases, a boat may even be lifted out of the water by a large crane with special slings. Other facility requirements include the usual repair shops.
- *Zone planning approach*—The work on all systems will be taking place in small, congested spaces. A well-planned zone approach is needed to facilitate coordination of the work force through these spaces.
- *Project management approach*—A small project team is sufficient. The team should be involved in the early planning

3.3.2 Case 2. Overhaul of merchant ships and noncombatant military ships is substantially larger in scale than Case 1. These ships have propulsion, auxiliary, cargo handling, communication/navigation, and habitability systems to be overhauled throughout the ship. Much of the equipment will be removed to shops for repairs and component testing. A major challenge is putting the ship back together again after having it in such a state of disassembly.

- *Facilities*—A dry dock, pier, cranes, and a full array of repair shops are required for an overhaul of this nature. Secure storage areas for both new and removed ship material are needed. Office facilities for the project team should be provided adjacent to the job site with a clear view of the ship and its access points.
- *Zone planning approach*—A zone technology approach is certainly dictated by the magnitude and diverse location of the work. However, it is also made necessary by the complexity of reassembling the ship with material and equipment that have been removed from the ship and stored, removed from the ship to a shop and repaired,

removed from the ship and sent to a subcontractor for repair, bought new or manufactured, or provided by the owner. Accountability for this great amount of material and equipment must be maintained throughout the process, and the material and equipment must be returned to the ship in time to support the reinstallation sequences and phased testing program. Each piece of equipment or material must be linked to its location and its place in the process by zone and by stage.

- *Project management approach*—A job of this nature requires a sophisticated project management team working with a large shipyard work force in a matrix



Overhauls

		Size	Complexity	Facilities	Planning Approach	Management Approach
Overhauls						
■ 1	Tugs, ferries, & other workboats	☒	☒	Shops/Pier/DD or Marine RR	Zone	Project
■ 2	Containerships, tankers, bulk carriers, & other cargo ships	▨	☒	Shops/Pier/DD	Zone	Project
■ 3	Cruise ships & military combatants	▨	▨	Shops/Pier/DD	Zone	Project & Matrix
Legend: Least Least to midrange Midrange Midrange to greatest Greatest						

Fig 9-23. Overhauls

matrix relationship. The project team should include members from all the major shipyard organizations to coordinate planning, material ordering, prefabrication, production, subcontractors, testing, trials, and contract management.

3.3.3 Case 3. Overhauls of highly complex ships, such as cruise ships and military combatants, are similar to and have much the same requirements as Case 2. However, they involve much more densely packed and complex systems, thereby increasing the level of sophistication needed in the approach. Cruise ships have intensely concentrated habitability systems and passenger comfort standards. Military combatants not only have state-of-the-art propulsion, weapon, fire control, communication, navigation, and computer systems, but most of those systems are redundant so the ship can continue to fight even if it sustains substantial damage. Combatants tend to be narrow and fine-lined to enhance their speed characteristics. This reduces the available volume for accommodating all the redundant systems and makes accessibility very difficult. Survivability of combatants is also improved by a proliferation of watertight boundaries, which further complicates working on systems that penetrate those boundaries.

- *Facilities*—The facility requirements are the same as Case 2, except additional facilities are needed for electronics, ordnance, gas turbines, variable-pitch propellers, and other special systems. Services for special systems can also be obtained from subcontractors. There is a substantial amount of special test equipment needed.
- *Zone planning approach*—The planning requirements are similar to Case 2, but more complex. This is especially true for the combatant ships where the work zones must be completed to support extensive test programs, crew training, and certification by various review boards. The propulsion system work and testing, leading up to a light-off examination by the crew, used to be the controlling part of a combatant overhaul. That position has now been usually replaced by the even more complicated integrated combat systems test and certification program.
- *Project management approach*—Case 2 once again provides the model for the project management team, except that it would be larger and include additional specialists in joinery and outfitting for cruise ships and in combat systems for combatant ships.

4. Conversion and Modernization

Conversion and modernization of both commercial vessels and naval warships are complex strategic, business, and waterfront production endeavors. Typical modernization and conversion projects include installation or removal of midbodies, cargo-handling upgrades, installation of improved bows, re-engineering work, habitability upgrades, environmental protection modifications, and military mission system upgrades. Figure 9-24 shows the conversion of an older tanker for contin-

ued use. This process, termed "jumboizing," utilizes the stern, machinery room, and existing house. Completely new (and usually larger) cargo tanks, pump room, and bow are joined to the stern, providing an additional 15 to 20 years of service to the shipowner at lower cost than completely new construction.

These types of projects are often technically challenging and require a substantial engineering effort. Conversion projects are also characterized by high material and equip-

ment costs and labor-intensive rip-out and installation. Items such as a new missile system for a modern cruiser, a new main propulsion unit in a re-engining effort, or steel for vessel lengthening are major expenditures. In some cases, installation cost is much more

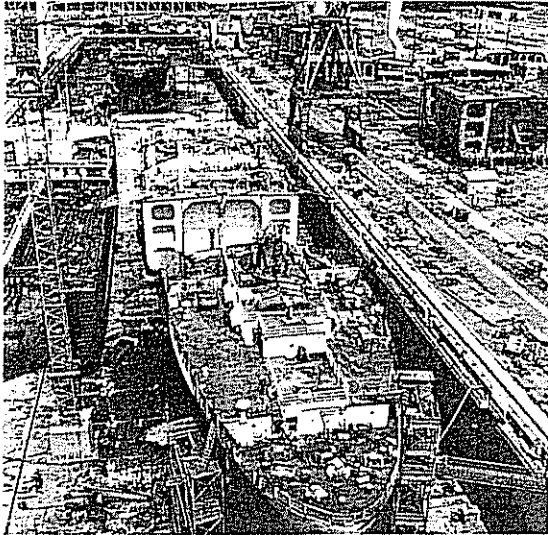


Fig 9-24 Conversion of an older tanker for continued use

than it would be in a new ship where installation could occur at a stage of construction when there was easy access. Rip-out, working around existing systems, transporting material through circuitous access routes, and additional safety precautions necessary for working around such hazards as fuel oil and live electrical systems force up labor costs substantially.

Whether to undertake conversion and modernization work is fundamentally a strategic business decision that may be considered several times during the life of a ship. This decision is influenced by external drivers (see Figure 9-25) that are similar for the private ship operator and the naval planner. Both consider and respond to competition and external threats, technological developments, changing mission requirements, and the age and material condition of the ship. The modernization/conversion decision is influenced by labor prices, material costs, government regulations, replacement costs, and competitor decisions and actions. The decision maker is ultimately faced with conducting

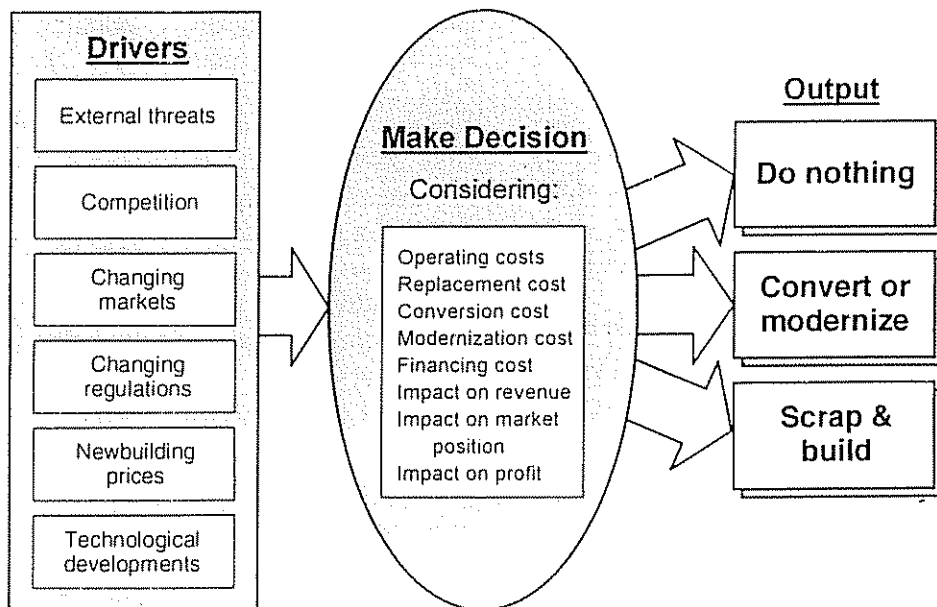


Fig 9-25. The conversion/modernization decision

a series of cost-benefit analyses on the various scenarios:

- Do nothing and continue to operate the ship as currently configured and in the same mission status
- Scrap the ship and build a replacement vessel
- Conduct the conversion or modernization project

As an example of this type of decision making, consider the recent actions of a major shipowner reacting to new government regulations, changing market conditions, and actions of competitors. The vessel in question was built in 1975 and was used primarily as a crude oil tanker until 1992.

In September of that year, the U.S. Coast Guard ruled that the shipowner would be required to conduct major repairs and upgrading if he were to continue to operate the ship as a crude oil tanker. These requirements were based on new safety and environmental regulations. The current oil-shipping market did not justify the capital investment to conduct the required upgrades, so the owner decided to alter the mission of the ship, employing it exclusively as a carrier of government grain cargoes.

In 1993, the federal government decided that it would discontinue the practice of moving grain in oil tankers. The shipowner was once again faced with a strategic and business decision in response to new government regulations and changing market conditions. His answer to this new situation was to undertake a conversion effort at a South Korean shipyard. The nearly 20-year-old oil tanker was converted to a dry bulk carrier for a cost of approximately \$7.5 million. The converted vessel was now eligible for the government-sponsored grain trade.

As an additional benefit the shipowner was able to negotiate and execute an option to convert a second oil tanker for a reduced price

at the same South Korean shipyard. Thus, the conversion price per hull was less and the owner's capital cost on a fleet basis was lower than for a single ship.

The aging of the world fleet is producing a need for more modern shipping capacity and forcing more of these types of decisions. As Figure 9-26 shows in a typical snapshot of the merchant fleet in 1992, the large number of ships built in the 1970s are nearing the end of their economic service life, and the small number built since appears to be insufficient to carry the current level of trade when the older ships are retired [4]. Fleet data are constantly reviewed by shipbuilding and repair marketing personnel in order to determine the demand for conversion or modernization versus new building. Since new building costs are high and world trade prospects continue strong, service life extension alternatives to new construction are attractive to a large number of shipowners and operators and are expected to provide continuing modernization and conversion work for ship repair companies.

Complexity is initially confronted during the basic and functional design processes for the proposed conversion or modernization, demanding creative and innovative solutions. During basic design, specifications that address the technical and performance requirements of the conversion or modernization project are developed. From these specifications and requirements, system diagrams and zone groupings are developed as part of the functional design process. These processes are very similar to those encountered during basic design and functional design on a new construction project, but are frequently more complex because of the following factors:

- Size and space considerations on the existing vessel
- Support system requirements for the new equipment

- Compatibility issues with other equipment that will remain on the ship
- Weight, moment, list, and trim limitations

Complexity in a conversion or modernization effort is addressed during the planning and execution of the project in some of the following ways:

- Identifying and segregating material into material-ordering zones and establishing appropriate linkages to the work control schedule
- Establishing zone boundaries and appropriate zone groupings
- Establishing appropriate linkages with the fabrication shops
- Planning, establishing, and maintaining proper flows of work
- Implementation of the zone-oriented organization and zone-oriented scheduling

- Developing schedules that are resource-based
- Integrating zone production schedules with system testing and certification requirements
- Planning and scheduling unique or high-value resources
- Estimating, costing, and progressing work via zone-oriented approaches
- Bench marking costs versus potential competitors
- Performing make or buy decisions
- Subcontracting or outsourcing portions of the project to reduce cost and speed up schedule

Where a large portion of work is focused in a single geographic area of the ship, integrated process lanes can be used to reduce time and cost. Zone-oriented planning also supports the creation of project or conversion work teams that cut across traditional trade jurisdictions. These teams should receive any nec-

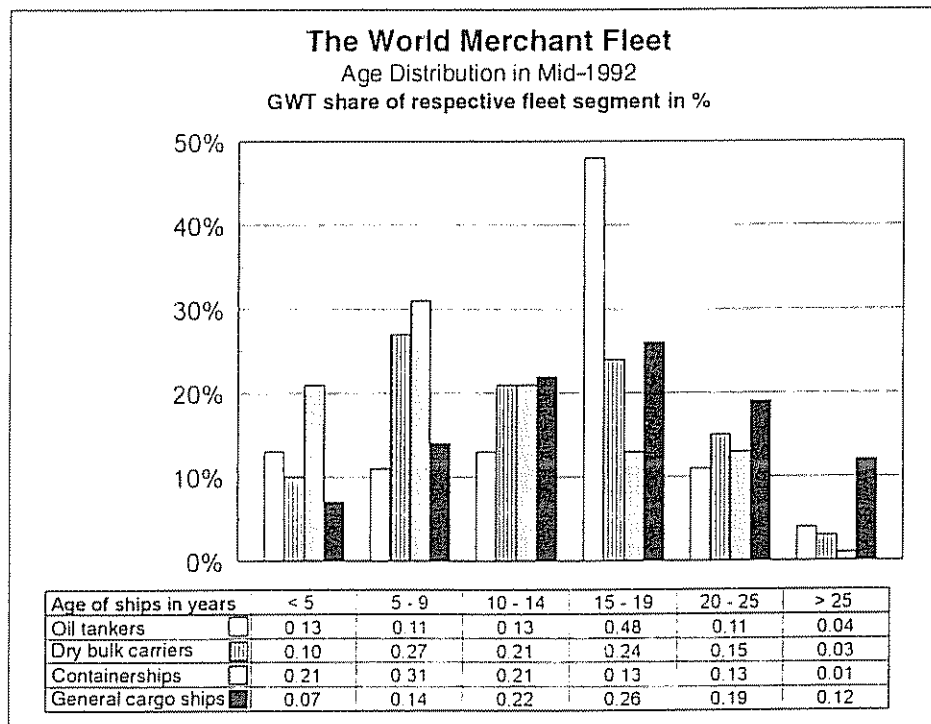


Fig. 9-26 World merchant fleet age distribution

essary specialized training, participate in the planning and packaging of work for their zones, and track schedule, cost, and progress by zone.

Since the range of technical solutions is so great for the potential problems of converting ships for other missions or modernizing them to extend their lives, six widely different examples of actual conversion/modernization projects are discussed here, are presented in Figure 9-27, and are plotted on an approach selection graph.

Because of their size and complexity, appropriate planning and management approaches for all these examples require zone planning and a sophisticated project management team. Most need the support of a large shipyard work force in a matrix relationship. The project team should include members from all the major shipyard organizations to coordinate planning, material ordering, pre-fabrication, production, subcontractors, testing, trials, and contract management, as well as appropriate specialists.

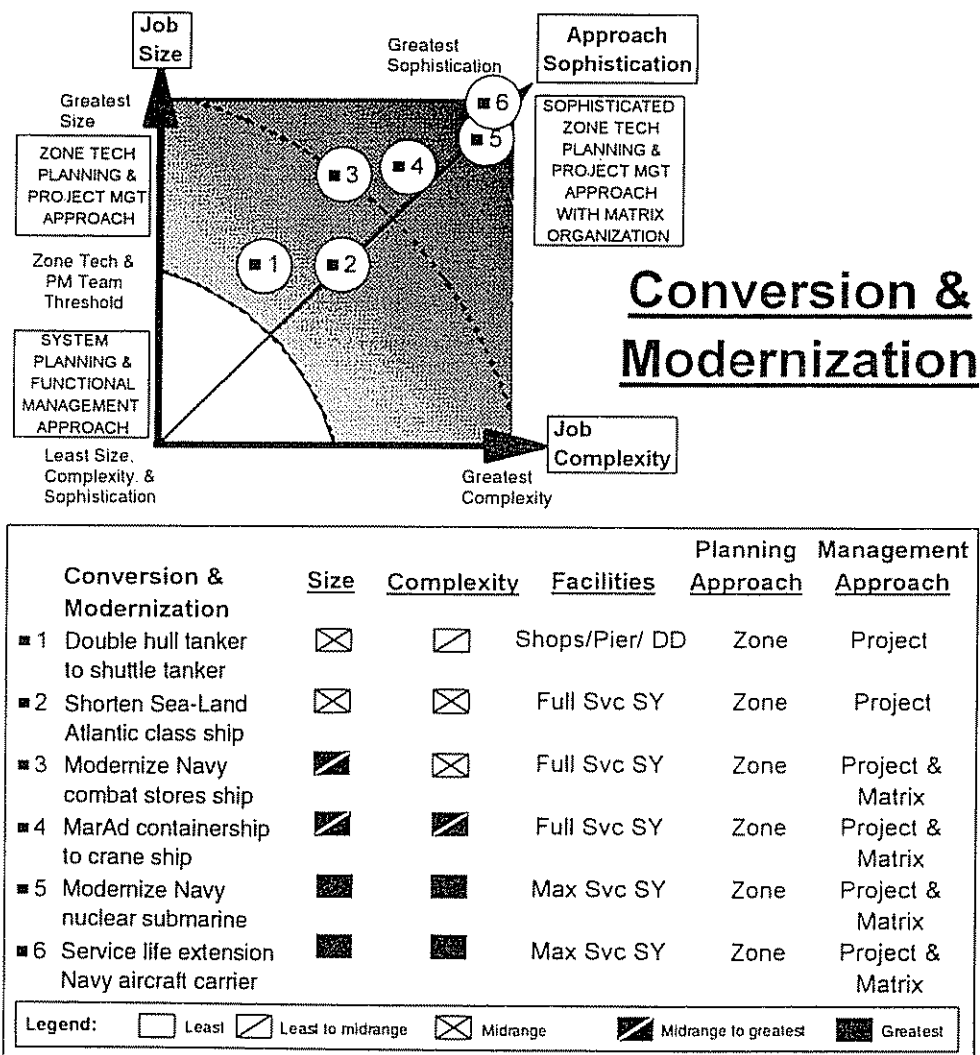


Fig 9-27 Conversion and modernization

The six example projects include the following:

- Conversion of a double-hulled Aframax tanker to a shuttle tanker
- Shortening Sea-Land Atlantic class vessels
- Modernization of a U.S. Navy combat stores ship
- Conversion of a Maritime Administration (MarAd) containership to a self-loading crane ship
- Modernization of a U.S. Navy nuclear-powered submarine
- Service life extension for a U.S. Navy aircraft carrier

Only the work scope is discussed since facilities, planning, and management approaches are the same for all six cases.

4.1.1. Case 1. The primary conversion work on this double-hulled tanker included installation of a bow loading system, bow and stern thrusters, controllable-pitch propeller, an additional diesel generator, a dynamic positioning system, and additional fire, safety, navigational, and communications equipment. The requirements were straightforward, employing commonly used equipment. The location of this equipment was designed to preclude any major access or interference problems. Overall, the job was moderate in size and not particularly complex. The project was completed in 60 days and the tanker was transformed into a full, dynamically positioned, shuttle tanker.

4.1.2. Case 2. The Sea-Land conversions changed the configuration of Atlantic class vessels to increase the speed of each ship by three knots to better serve selected markets. The complexity of the design work on the Sea-Land Atlantic class ship was more demanding than the shuttle tanker. A new, more streamlined bow section had to be designed and model tested. The ship was shortened by removing

a 40.74-meter midbody section and reconfigured by installing the new bow section, diesel generator, and controllable-pitch propeller. These changes increased the service speed of the ship from 18 to 21 knots. The job was considered to be only moderately large and complex. The conversion of three ships will be completed in six months.

4.1.3. Case 3. The modernization of a U.S. Navy combat stores ship involved cargo handling and major habitability upgrades. The modernization work package also included installation of two cargo elevators, several dry dock repair items, and modifications to the civilian living spaces. The effort was large, but only moderately complex. The modernization was completed in nine months.

4.1.4. Case 4. The conversion of a MarAd container/cargo ship to a self-loading crane ship was a major initiative at two successive shipyards. The primary conversion work on the project included installation of two Hagglund model 3637 crane systems, including building new support structure all the way to the bottom of the ship. Other major work included new diesel generator installation, new switchboards and electrical wiring the length of the ship, new after-crane, LP turbine re-bucketing, boiler repairs, cargo hold modifications, installation of permanent ballast in 10 tanks, rerouting of all tank piping, cargo hatch cover repairs and preservation, hull repairs and painting, and substantial tank repairs. The conversion was a technically demanding project, because weight, moment, and trim considerations were major factors in the installation of the two large cranes. Complete support system evaluations were required, especially in the areas of electrical power and hydraulics. This project was made much more difficult by being started at one shipyard, being stopped by the government due to funding problems, and having the ship laid up for two years with all the systems

open and the new cranes stored in the wet cargo holds. The ship was finally brought to the second yard in a deteriorated condition with the removed material scattered about and the work scope unknown. This job was considered large and much more complex than it should have been. The project was completed in 20 months at the second yard.

4.1.5. Case 5 Nuclear-powered submarines are more complex technological vessels than NASA space ships. The modernization of a 688 class nuclear-powered submarine presented complex technical issues to the program team. The sonar and fire control system upgrades produced system interface requirements that generated the need for a substantial test and system certification program. Installing new equipment on-board resulted in a complete evaluation of support system requirements, including electrical power, hydraulics, air-conditioning, chilled water,

high pressure air, and seawater cooling. Weight, moment, list, and trim considerations were also key factors because of the submarine's operating environment within a submerged operating envelope. Also required were the replacement of components in the nuclear propulsion plant and extensive repair work. This was a large, very complex job. This project was completed in 12 months.

4.1.6. Case 6 Because of their tremendous cost, aircraft carriers are designed to last longer than most other ships. The aircraft carrier Service Life Extension Program (SLEP) projects were designed to extend the service life of the Forrestal class aircraft carriers even further (from 30 years to 45 years). These huge modernization projects were challenging simply because of the sheer scale of the effort. They were so big that in the initial zone breakdown (shown in Figure 9-28), each zone was called a mini-ship [7]. Communications

U.S.S. Constellation (CV-64) Zone Boundaries

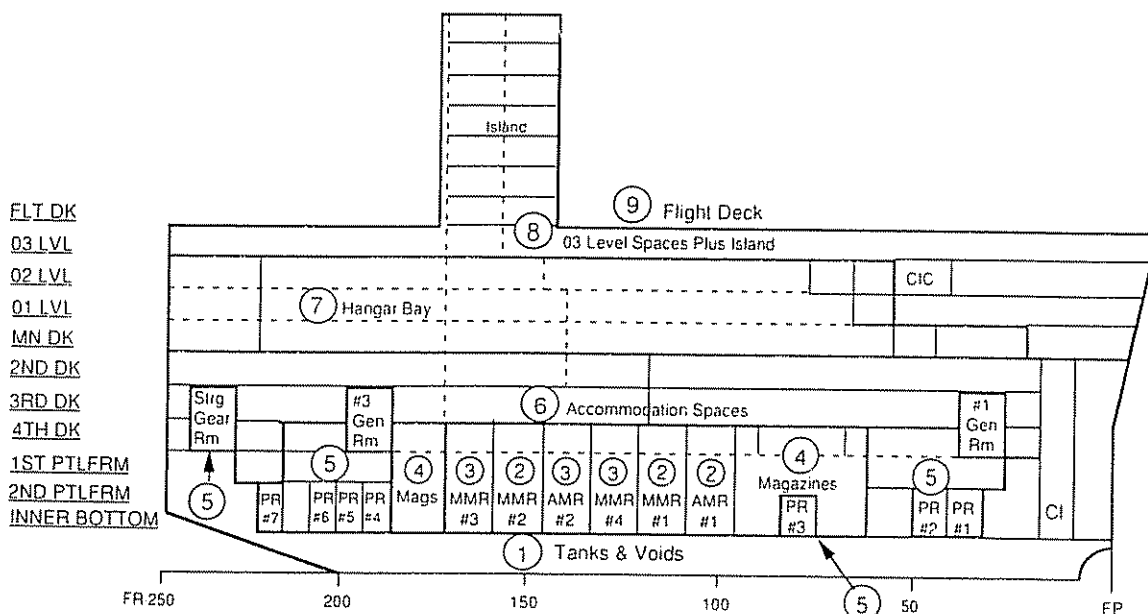


Fig 9-28 Initial zone breakdown

equipment, radar systems, avionics, fire control systems, and weapons elevators were all modernized. Catapults, arresting gear, jet blast deflectors, and aircraft elevators were all overhauled. Major propulsion systems were overhauled, as well as numerous tanks, voids, pump rooms, and the underwater hull. Space and access considerations were difficult. A comprehensive review of all support system requirements was necessary due to the large number of newly installed components and the radically changed system

configurations. Another vital consideration in the new systems designs was that they would have to support future modernization projects with increasing demands. The ship would now operate well into the next century and would be required to face new threats and changing mission scenarios. This project was considered to be massive and very complex. The duration of a SLEP project is approximately 28 months. To date, all SLEP projects have been accomplished only at naval shipyards.

5. Deactivation

Lay-up and deactivation of active ships provides additional work for companies in the ship conversion, overhaul, and repair market. The purpose of this type of work is to prepare ships for inactive storage and to maintain them while in storage, so that they can be effectively returned to service in time of strategic need or national emergency.

MarAd's National Defense Reserve Fleet (NDRF) is a principal source for this type of work. In 1993, MarAd had 96 ships in its Ready Reserve Force (RRF), with an expectation to expand to 140 ships by 1999. MarAd provides funds for the procurement, lay-up, and maintenance of this force, which is in a state of readiness to meet 5-, 10-, or 20-day activation schedules.

A second major source of deactivation work is U.S. Navy ships and submarines. This source of work has been growing in recent years with the steadily decreasing size of the active fleet. The Navy has retired primarily vessels that were older and increasingly more expensive to operate. The active fleet declined to 473 ships by the end of FY92, and to 450 ships as of June 30, 1993. It is contemplated that the size of the active fleet could go down to 346 ships by 1999. This reduced fleet would include 11 aircraft carriers, one reserve/training aircraft carrier, and 45 to 55 attack submarines.

This type of work is not typically complex and can frequently be accomplished pierside with limited facilities. The work generally consists of machinery and tank lay-up, installation of temperature- and humidity-control devices, and required repair work to ensure rapid and successful reactivation of the ship should activation be ordered. The complexity of the effort is greatly expanded if the vessel is nuclear-powered. In the case of nuclear-powered ships, additional support services and specialized personnel are required. These specialized personnel would include nuclear engineers, radiation control personnel, and nuclear defueling personnel.

Deactivation projects are frequently planned in a system or modified zone approach. The nature of the work typically consists of several stand-alone pieces of work that do not impact a large number of support system boundaries. Access and interference between various trades are not typically encountered. A system-oriented planning approach can, therefore, be beneficial for this type of work.

Frequently, several tasks within a particular geographic zone are planned for execution concurrently by the same work team. This type of modified zone approach produces good results because trade resources can be more effectively employed on a wide variety of tasks within a specific geographic zone.

The management approach for this type of work is frequently a project approach. The deactivation project team is responsible for the planning, execution, and overall performance of the project. Once again, the project

approach builds on a revenue center orientation for the management of work. The project team can adopt the modified zone approach for planning the project and package tasks for execution within a particular zone.

6. Scrapping

Shipbreaking and scrapping are attractive endeavors when steel and used equipment prices are high and when ready markets exist for quick conversion of scrap to other products. Shipbreaking and scrapping are labor-intensive activities that require high productivity and competitive wages in order to be financially viable. This type of work has been conducted mostly in developing countries in recent years (see Figure 9-29), but the market has been changing due to the declining steel market and increasing wages.

The projected annual market for shipbreaking and scrapping is expected to grow to 38 million DWT by 1999 [3]. This market is valued in excess of \$1 billion annually, worldwide, until the end of the 1990s.

This forecast for a growing shipbreaking market is based on the age of the current worldwide fleet and the increasing incidence of structural and mechanical problems associated with these aging vessels. Additionally, insurance premiums are rising for many of these older ships, making them even more expensive to operate.

Effective shipbreaking projects require creative planning, special tooling, strict labor controls, and high productivity in order to be financially successful. The zone approach to planning the scrapping of a ship is the desired

mechanism for producing a sound and effective scrapping plan. Initially, the ship should be strategically divided into zones for scrapping by zone-oriented work teams. Some of the factors that should be considered when dividing the ship into zones should include:

- Rotating machinery that requires removal for resale or reuse on other vessels,
- Electrical/electronic components to be removed
- On-board liquids to be drained and properly disposed of
- Asbestos present by geographic location
- PCB's present by geographic location
- Special system lay-up requirements

After strategically planning the scrapping zones, work must be packaged and scheduled for execution by multiskilled work teams. These teams should be trained and equipped to perform a wide variety of tasks in a rapid manner, with minimal supervision. High productivity, with minimal labor expenditures, is the primary goal of scrapping projects. Size and complexity of a scrapping job is usually proportional to the size and complexity of the ship being scrapped, though the presence of hazardous waste products seriously complicates any job.

7. Recent Innovations in Ship Repair

Like shipping, the ship repair, conversion, and modernization business is a very competitive industry. With shipowners trying to drive down their costs and the shipyards com-

peting for their business, an environment has been created that generates innovative ideas for achieving improved operating results and more competitive business positions. Some

Analysis of Vessels Broken Up in 1992
(Developing countries are in the lead)

	No	Total dwt ('000)	No	Tankers dwt ('000)	No	Dry Bulk dwt ('000)	Gen. Cargo No	Ships dwt ('000)
China	36	3,187	15	2,442	12	666	9	79
India	109	2,733	32	1,528	13	420	64	785
Bangladesh	34	1,727	12	1,370	3	113	19	243
Pakistan	20	1,715	13	1,472	4	214	3	29
Turkey	7	185	2	106	2	41	3	38
Thailand	1	15	—	—	—	—	1	15
Mexico	1	13	—	—	—	—	1	13
Spain	2	5	—	—	—	—	2	5
Peru	1	3	—	—	—	—	1	3
Greece	1	3	—	—	—	—	1	3
Portugal	1	2	—	—	—	—	1	2
Denmark	2	2	—	—	—	—	2	2
Japan	2	1	—	—	—	—	2	1
Netherlands	1	1	—	—	—	—	1	1
Germany	1	1	—	—	—	—	1	1
United Kingdom	1	1	—	—	—	—	1	1
TOTAL	220	9,593	74	6,919	34	1,453	112	1,221

Source: Lloyd's Shipping Economist Research files London

Fig 9-29. Analysis of vessels broken up in 1992

recent ideas and innovations for both managing and delivering ship repair services will be needed

7.1 Maintenance Management Approaches

Preventative maintenance, an approach of providing maintenance for equipment before it breaks down, has long been a mainstay of ship maintenance programs designed to minimize out-of-service time. Life cycle/equipment failure data are routinely available for most equipment and can be used as the basis for determining maintenance intervals in a preventative maintenance program. Now, planning for preventative maintenance can be enhanced with more specific data from Predictive Maintenance (PDM).

PDM is an innovation in the ship repair industry that uses vibration monitoring and analysis of equipment to provide insight into the current condition of a piece of equipment and to predict imminent catastrophic failure of vital machinery. This type of program is particularly attractive to shipowners and operators because it:

- Increases equipment availability by maximizing running time between equipment overhauls
- Increases ship operating time by reducing urgent maintenance due to catastrophic failures of critical equipment
- Allows more efficient repairs because repair quality can be checked

- Reduces spare parts inventory because adequate lead time now exists for parts identification and procurement
- Improves operator and public safety
- Provides data for preventative maintenance programs

Tools required for vibration analysis include a transducer, a data collector, and PC-based hardware and software for data analysis. This concept can be extended through use of satellite communication links connecting a ship's PDM computer to a central monitoring station for overall engineering monitoring and response.

Continuous maintenance is a concept that, when combined with PDM and preventative maintenance, is attractive to ships where downtime is prohibitively expensive. This is particularly the case with commercial cruise ships and military aircraft carriers.

Continuous maintenance is accomplished by a riding crew, performing as much maintenance at sea as is possible, while the ship continues to operate. Both predictive and preventative maintenance are planned and accomplished, along with any unscheduled repairs that can be done underway. The riding crew will also do as much rip-out, layout, and other preparation as possible for required in-port maintenance and surveys.

7.2. Delivery of Services

The manner in which repair services are delivered in the ship repair industry is also undergoing experimentation and innovation. A shipowner may establish an organization that can provide much of its own maintenance services. Alternatively, the owner may sign a long-term contract with a single service provider to handle repair and maintenance on a one-stop-shopping basis. Shipyards may not just wait until the ship arrives and solicit bids. They may instead enter into long-term service contracts for a ship or group of ships in a class, helping with

work identification, maintenance records, spare parts storage, and performance of both planned and unscheduled maintenance. "Tiger teams" could be ready on short notice to fly wherever the ship is located to handle most emergency repairs. A shipyard may offer (for a fee) long-term service guarantees for the ships that it builds, converts, modernizes, or overhauls, much as automobile manufacturers and dealers do.

7.3. Technological Trends

Rapid technological advances have led to changes in materials used on ships, repair processes, propulsion systems, ship design, and electronics. Some new technology has resulted from safety and environmental regulation. Arguably, the greatest changes have been in information technology. All these technological changes will affect the ship repair, overhaul, modernization, and conversion services required in the future.

7.3.1. New Materials New composite materials are being used for special-purpose craft such as minesweepers and for deckhouses and other structures up high on a ship. These structures need to be lightweight to keep the center of gravity low. Repair of vessels made with these materials require processes, skills, and equipment not now in common usage. There will also be cases where shipowners will want to take advantage of these materials for modernization and conversion of existing ships.

Coatings comprise another material category experiencing rapid change. New types of coatings with longer endurance, greater antifouling capability, improved corrosion resistance, faster drying times, reduced toxins, or easier application characteristics are continuously being introduced into the market. Because of coatings' susceptibility to damage and deterioration, their repair or replacement is virtually always part of any repair work package. Often, a dry-docking needed

for other purposes is used as an opportunity to upgrade the coatings and take advantage of the latest technology. Safety and environmental regulations related to coatings are a major factor in the ship repair and maintenance industry also. The industry not only has to comply with all the rules concerning coating application (as do new construction yards), but also the rules for disposal of toxic and hazardous wastes generated from the removal of old coatings containing such materials as lead and organo-tins.

7.3.2. New Processes Because of the unique nature of much ship repair, application of automated procedures has traditionally been limited. Gradually this is changing in some areas where simple robotics are starting to be used for welding, cleaning pressure vessels, and doing other work in places where access is difficult or impossible for humans. There is much room for progress. However, advances continue to be made in tool and equipment design, improved scaffolding, and environmental controls.

7.3.3. Ship Design and Propulsion Systems New ship designs with radical hull forms, unique superstructure, or novel machinery arrangement all pose new challenges to the repair, overhaul, modernization, and conversion industry in the future. These include:

- Ships' superstructure and hull form being designed so aerodynamically that they must be model-tested in a wind tunnel
- Open-topped containerships that were recently built in Germany
- Ships 600 to 800 feet long designed with semiplaning hulls
- Small waterplane area, twin-hull (SWATH) ships built for applications requiring greater stability at sea
- Ships equipped with flapped rudders to enhance maneuverability

- Diesel designs, with engines producing 900-1200 kW at 750-1,000 rpm, that can have much more extensive repair and overhaul work done on them while the ship is underway
- Gas turbine engines in need of repair that can often be removed and replaced for fast turnaround, while the damaged engine is sent back to the factory for repairs
- New jet engines that provide water jet propulsion without cavitating propellers. The jet engines will need new techniques for repair. In some cases, ships might be retrofitted with one of these propulsion systems during modernization or conversion.

7.3.4. Electronics Warships have become so sophisticated electronically that the electronic test program has become the critical item in most scheduled maintenance availabilities. Commercial ships have lagged behind warships in this area, but are rapidly incorporating new electronic technology for navigation, communications, propulsion controls, cargo management, alarm systems, and maintenance analysis. State-of-the-art ship control centers (single point bridge systems that embrace all navigation, engine control, and communications functions into a packaged center) are already installed on some ships. This trend will increase the importance of electronics in maintenance and repair programs and will generate a demand for retrofit of some of these systems on existing commercial ships. Much marine electronics work is currently done by specialist subcontractors to the ship repair contractor.

7.3.5. Regulatory Requirements Safety and environmental regulations, both U.S. and international, are becoming more stringent and having more impact on the design and outfitting of ships. Sometimes, when regulations change, the new equipment configuration must

be retrofitted to existing ships. Compliance may mean changes to tanks, new double bottoms, creation of new temporary storage, installation of new sewage treatment plants, stack gas omission controls, or addition of new emergency equipment.

7.3.6. Information Technology. There are now available interactive software packages with programs covering the various aspects of a lifetime of ship care. The repair and maintenance programs are designed to work with a personal computer aboard a ship. The hull condition monitoring and protective coating programs provide instant update of hull condition with pictorial displays of each surface showing corrosion, coating condition, and extent of pitting and cracking, together with details of scantlings as new and showing their renewal limits. Another program can be connected with sensors and strain gauges at strategic points in a ship's structure to provide real-time motion and stress information. A shore-based service providing 24-hour technical analysis and crisis management sup-

port can be connected by radio to the on-board computer.

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GLOSSARY

- Acceleration.** The efforts required to prevent a delay in ship delivery, or to achieve a major milestone (e.g., increased manning, added shifts, overtime, rescheduling of work force), or to achieve a milestone earlier than originally scheduled.
- Access holes.** Temporary holes cut in ship's structure to allow access and shifting of equipment into position during construction.
- Accommodation.** All spaces on a ship that are associated with the crew's normal living, including navigation, radio, and similar spaces when incorporated in the same deckhouse.
- Accuracy control.** The use of statistical techniques to monitor, control, and continuously improve shipbuilding design details and work methods so as to maximize productivity.
- Aft.** Toward, at, or near the stern.
- After body.** That portion of the ship's hull aft of amidships.
- Afterpeak.** The compartment in the stern, aft of the aftermost watertight bulkhead.
- Air and drainage holes.** Holes cut in the structure, usually transverse webs, to ensure the free escape of air to the vents and free drainage of liquids to the pump suction wells.
- Amidships.** A point which is exactly halfway between the fore and after perpendiculars.
- Anchor.** A device, usually of steel, used to hold a ship against the movement of current, tide, and wind.
- Angle or angle bar.** A structural section made up of a web and a flange, that is used as a stiffener.
- Appendages.** The portions of a vessel extending beyond the main hull outline, including such items as rudder, shafting, struts, bossings, and bilge keels.
- Aperture.** A recess in which the propeller is located.
- Assemble.** To fit and join parts together.
- Assembly.** *See* Subassembly.
- Athwartship.** Across the ship, at right angles to the fore and aft centerline.
- Auxiliary machinery.** Various pumps, motors, generators, and other equipment required on a ship, as distinguished from main propulsive machinery units.
- Back gouging.** The forming of a bevel or groove on the back side of a partially welded joint to assure complete penetration upon subsequent welding from that side.
- Ballast tank.** Watertight compartment to hold water ballast.
- Bars.** Basic structural members of a ship, usually steel, of certain standard shapes; a shape in any bar of constant cross section throughout its length such as a channel, T bar, or angle bar.
- Baseline.** An imaginary horizontal line, drawn through the molded hull of the vessel, often the keel, from which vertical distances may be measured.
- Beam, cant.** A term applied to the beams supporting the deck plating in the overhanging portion of the stern. These beams radiate in fan shape formation from the cant frames to the transom.
- Beam, deck.** A horizontal structural member, usually a rolled shape, supporting a deck or flat.
- Beam, knee.** A bracket between a deck beam and frame.
- Beam, molded.** The maximum breadth of the hull measured between the inside surfaces of the side shell plating.
- Beam, transom.** The aftermost transverse side

- frame. Aft of it and connected to it are the cant beams.
- Berth. Where a ship is docked or tied up; a place to sleep aboard ship; a bunk or bed
- Bevel. The angle between the flanges of a frame or other member; also an angled edge on a structural member used to facilitate welding.
- Bevel, closed. A term applied where the flange of a bar is bent to form an acute angle with the web.
- Bevel, open. A term applied where the flange of a bar is bent to form an obtuse angle with the web.
- Bilge. Curved section between the bottom and the side of the vessel; also the lowest part of a vessel's internal spaces into which water drains
- Bilge and ballast system. A piping system generally located in holds or lower compartments of a ship and connected to pumps or eductors. This system is for pumping overboard accumulations of water in holds and compartments and also for filling and emptying ballast tanks
- Bilge blocks. Blocks set under the bilge for support during construction or dry docking.
- Bilge bracket. A vertical transverse plate welded to the tank top or margin plate and to the frame in way of the bilge area.
- Bilge keel. A vane mounted on the outside of a ship at the turn of the bilge normal to the hull to reduce rolling.
- Bilge plates. The curved shell plates that form the bilge
- Bilge strake. The hull plates that compose the curved sections that make the transition from bottom shell to side shell
- Bitt, mooring. Short posts (usually two) attached to the deck for the purpose of securing mooring or towing lines
- Bitumastic. An elastic bituminous cement usually found in fresh water tanks, used in lieu of paint to protect steel.
- Block. A section of a ship structure which is a three dimensional entity. Blocks are combined to form a ship during erection, and are normally the largest sections to be assembled away from the erection site.
- Blue sky. In the open; not under a roof or other protection from the weather.
- Blue sky outfitting. Outfitting done in the open during hull erection, e.g., landing outfit units or components before a space is enclosed
- Body. Refers to the hull; all volume from the upper deck down.
- Bollard. A mooring bitt.
- Booby hatch. An access hatch from a weather deck protected by a hood from sea and weather; also called companionway
- Boom. A round spar hinged at its lower end, usually to a mast or a crane, and supported by a wire rope or tackle from aloft to the upper end of the boom. Cargo, stores, etc., are lifted by tackle leading from the upper end of the boom
- Boom table. A stout, small platform, usually attached to a mast or crane to support the end of booms and to provide proper working clearances when a number of booms are installed around one mast; also called a mast table
- Bosom piece. A strap formed by a short piece of angle attached inside a butt joint of two angles
- Bossing or boss. The curved swelling outboard portion of the ship's shell plating that surrounds and supports the propeller shaft; also called propeller bossing/boss.
- Bossing plate. Steel plate covering the bulged portion of the hull where the propeller shaft passes outboard
- Bow. Forward end of a ship.
- Bracket. A structural member used to rigidly reinforce two or more structural parts, which are joined at approximately right angles to each other, such as deck beam to frame, or bulkhead stiffener to the deck or tank top; usually a plate
- Break. The end of a partial superstructure such as a poop, bridge, or forecastle where it drops to the deck below; any sharp change in a vessel's line
- Breakwater. Plates fitted on a forward weather deck to form a V-shaped shield against water that is shipped over the bow.
- Breasthook. A triangular plate bracket joining port and starboard side stringers at the bow
- Bridge, flying. The platform forming the top of the pilothouse
- Bridge, navigating. The conning station or command post of a ship
- Bridge house. A part of the upper superstructure of a ship. The officers' quarters, staterooms, and accommodations are usually located in the bridge house and the pilothouse located above it
- Bulbous bow. A bow with a rounded, protruding shape at the bottom to improve flow and resistance characteristics
- Bulk carrier. Ships designed to carry bulk cargo, usually not in liquid form, such as coal, ore, grain, etc
- Bulkhead. A vertical partition, which subdivides the interior of a ship into compartments or rooms. Bulkheads which contribute to the strength of a vessel are called strength bulkheads; those which are essential to the watertight subdivision are watertight or oiltight bulkheads. Gastight bulkheads serve to prevent the passage of gas or fumes

- Bulwark** Fore and aft vertical plating immediately above the upper edge of the sheer strake.
- Bumped** A term applied to a plate which has been pressed or otherwise formed to a concave or convex shape used for heads of tanks, boilers, etc.
- Burning** Oxy/gas, plasma-arc, or laser cutting, usually of shell plating or structural sections.
- Butt** The joint formed when two parts are placed edge to edge; the end joint between two plates; also transverse joints for connecting two parts, subassemblies, or blocks.
- Butt strap** A strap that serves as a connecting strength strap when it overlaps the butt between two plates.
- CAD** Computer aided design.
- CAM** Computer aided manufacturing.
- Cant frame** A frame which is not square to the keel line, such as stern frames.
- Cargo hatch** An opening in a deck for vertical loading and unloading of cargo holds.
- Cargo port** An opening in a ship's side for loading and unloading cargo.
- Casing, engine and boiler** Bulkheads enclosing a large opening between the weather deck and the engine and boiler rooms. This permits installing or removing large propulsion units such as boilers or turbines.
- Centerline** A vertical reference plane running fore and aft, dividing the ship into two symmetrical halves.
- Center vertical keel** A vertical girder running from the flat keel to the tank top along the centerline.
- Chafing plate** Bent plate for minimizing chafing of ropes as at hatches.
- Chain locker** The compartment in the forward or aft lower portion of a ship in which anchor chain is stowed.
- Chain pipe** Pipe for passage of chain from the anchor windlass to the chain locker.
- Chamfer** To cut off the sharp edge of a 90° corner; to trim to an acute angle.
- Chock** A cut piece of plating used to terminate a structural shape at its end or to support a structural shape; also an opening or guide for a towing or mooring line.
- Chock, boat** A cradle or support for a lifeboat.
- Clip** A short length of angle used by shipfitters to align structural sections.
- Coaming** The vertical plating bounding an opening for the purpose of stiffening the edges of the opening. It also retards the entry of water.
- Cofferdam** Narrow void space between two bulkheads or floors that prevents leakage between the adjoining compartments.
- Come along** A hand-operated lever hoist used during shipfitting for pulling together or supporting ship's parts or subassemblies.
- Companionway** An access hatchway in a deck, with a ladder leading below, generally for the crew's use.
- Compartment** A subdivision of space or room in a ship.
- Compartmentation** The subdividing of the hull by watertight bulkheads so that the ship may remain afloat under certain conditions of flooding.
- Container ship** A ship designed to carry cargo containers in holds and on deck.
- Cost/schedule control system (C/SCS)** Any system used by a U.S. government contractor in planning and controlling the performance of a contract. A C/SCS is predicated on a logical breakdown of contract work into discrete work packages.
- Covered electrode** A filler metal electrode used in arc welding, consisting of a metal core (usually steel) with a covering that protects the weld puddle from the atmosphere, improves the properties of the weld metal, and stabilizes the arc; also called a stick or rod.
- Cowl** *See* Ventilator cowl.
- Cradle** A support form in which a ship rests during launching.
- Crane** A device for lifting and moving heavy weights by means of a movable projecting arm and/or a horizontal beam.
- Critical Path Method (CPM)** Scheduling methodology that determines which sequence of tasks within a project requires more time to accomplish than any other sequence, based on the anticipated duration and interrelationships of all tasks in the project.
- Davit** A crane arm for handling lifeboats, anchors, stores, etc.
- Dead cover** A metal cover to close or protect an air port in case of heavy weather, to avoid glass breakage.
- Deadlight** A metal cover fitted inside a porthole to prevent the ingress of water if the porthole leaks, or the glass becomes broken.
- Deck** A horizontal surface in a ship corresponding to a floor in a building. It is the plating, planking, or covering of any tier of beams in either the hull or the superstructure of a ship. Decks are usually designated by their location, as boat deck, bridge deck, upper deck, main deck, etc.

- Decks at different levels serve various functions; they may be either watertight decks, strength decks, or simply cargo and passenger accommodation decks.
- Deck height. The vertical distance between the molded lines of two adjacent decks.
- Deckhouse. A comparatively light structure, built on the hull, which does not normally extend from side to side of the ship. It commonly is composed of spaces that are used for crew accommodations and control of the ship (bridge, radiator room, etc.).
- Deck machinery. Miscellaneous machinery located on the decks of a ship such as windlasses, winches, etc.
- Deck stringer. The strake of deck plating that runs along the outboard edge of the deck; also called stringer plate.
- Declivity. Inclination of the ways on which some ships are built and down which they slide during launching.
- Deep tanks. Tanks extending from the bottom or inner bottom up to or higher than the lower deck. They are often fitted with hatches so that they may also be used for dry cargo in lieu of fuel oil, ballast water, or liquid cargo.
- Depot-level. Used to describe repair and maintenance actions on military ships, temporarily taken out of service, that must be accomplished at a repair facility.
- Derrick. A device for hoisting and lowering heavy weights, cargo, stores, etc.
- Docking brackets. Short transverse flanged plates in the inner bottom structure that run from the center vertical keel to the first longitudinals on both sides of the keel. They usually alternate with the floors (see Floor).
- Dog. A small metal device used to secure doors, hatch covers, manholes, etc., in a closed position.
- Double bottom. Compartments at the bottom of a ship between inner bottom and the shell plating, mostly used for ballast water, fresh water, or fuel oil.
- Doubling plate. A plate fitted outside or inside of another to give extra local strength or stiffness.
- Draft marks. The numbers which are placed on each side of a ship at the bow and stern, and sometimes amidships, to indicate the distance from the lower edge of the number to the bottom of the keel or other fixed reference point. The numbers are 6 inches high and spaced 12 inches bottom to bottom vertically. Draft marks may alternatively be provided in meters.
- Drag lines. Wire ropes attached to temporary pads or chains attached to a ship to provide means of arresting the motion of a ship when it is launched.
- Dry cargo ship. A ship designed to carry dry cargo in units, often stowed on pallets and not carried in bulk.
- Edge preparation. A contour prepared on the edge of a plate or member to facilitate welding. Often an included angle of 10 or 30 degrees.
- Eductor room. A pump room to transfer liquid cargo.
- Electric arc welding. A standard welding process used in shipbuilding and repair work. An electric arc is formed when an electric current passes between two electrodes separated by a short distance from each other. In electric arc welding one electrode is the welding rod, while the other is the metal (plates, etc.) to be welded. The temperature is about 4000° C, the current flow between 20 and 600 amperes.
- Engine room. The location of main propulsion and some auxiliary machinery on board a ship.
- Ensign staff. A flagstaff at the stern.
- Equivalent manning. The total manhours (straight time) recorded daily, weekly, or monthly divided by the standard number of hours in the period.
- Erection. The placing and connection on the ways or other building position of subassemblies, blocks, and/or outfit units of a ship.
- Escape trunk. A vertical trunk fitted with a ladder to permit personnel to escape when trapped, usually located in the aft end of the vessel between the shaft tunnel and the upper decks.
- Fabricate. To process materials in the shops, to create parts needed for both hull and outfit assemblies. In hull work, fabrication consists of cutting (shearing), shaping, punching, drilling, countersinking, scarfing, rabbeting, beveling, and welding.
- Face plate. Generally a narrow stiffening plate fitted along the inner edge of web frames, stringers, etc., to form the flange of the member.
- Fair. To align the parts of a ship so that they will be without kinks, bumps or waves; to remove distortion from parts or assemblies.
- Fairhead or fairlead. A fitting device used to preserve or change the direction of a rope so that it will be delivered on a straight line to a sheave or drum.
- Fairwater. A term applied to plating fitted around the ends of shaft tubes and strut barrels, and shaped to streamline the parts, thus eliminating abrupt changes in the water flow.

- Fall.** The rope used with blocks to make up a tackle. The end secured to the block is called the standing part and the opposite end, the hauling part.
- Fantail.** The overhanging stern section of a ship's after end which extends well aft of the after perpendicular; also called counter stern.
- Fashion plate.** Bulwark aft of the bow and above the forecastle deck.
- Fender.** A device built into or hung over the side of a ship to prevent the shell plating from rubbing or chafing against other ships or piers.
- Fidley.** The top of the engine and boiler room; casings on the weather deck; a partially raised deck over the engine and boiler casings, usually around the smokestack.
- Fish head.** A plate clamp, self-locking, used on cranes to lift plate.
- Fixed light.** A circular non-opening window with glass in the side of a ship, door, skylight cover, etc.
- Flange.** The part of a plate or shape bent at right angles to the main part; to bend over to form an angle.
- Flat.** A small partial deck or a machinery level, usually built flat.
- Floor.** Vertical transverse plate immediately above the bottom shell plating, often located at every frame, extending from bilge to bilge.
- Fore.** A term used in indicating portions or that part of a ship at or adjacent to the bow.
- Fore and aft.** In line with the length of the ship; longitudinal.
- Forebody.** That portion of the ship's body forward of the midship section; entrance.
- Forecastle.** A superstructure fitted at the extreme forward end of the upper deck.
- Forefoot.** The lower end of a ship's stem which curves to meet the keel.
- Forepeak.** The watertight compartment at the extreme forward end.
- Forward.** In the direction of the bow.
- Foundation.** A structural support for equipment and machinery installed on a ship. The structural supports for the boilers, main engines or turbines, and reduction gears are called the main foundations. Supports for auxiliary machinery are called auxiliary foundations.
- Frame.** A term used to designate one of the transverse members that make up the riblike part of the skeleton of a ship. The frames act as stiffeners, holding the outside plating in shape and maintaining the transverse form of the ship.
- Frame spacing.** The fore and aft distance, heel to heel or web to web, of adjacent transverse frames, depending on the shape or frame used.
- Freeing port.** An opening in the lower portion of the bulwark which allows water on deck to drain overboard.
- Funnel.** A chimney through which combustion products are led from propulsion and auxiliary machinery to the weather. Also called the stack or smokestack; frequently contains other things (e.g., fan rooms, etc.) or may be a "dummy" for appearance only.
- Furnaced plate.** A plate that requires heating in order to be shaped.
- Galley.** A cookroom or kitchen on a ship.
- Gateway.** A passageway, side shell opening, and ladderway used for boarding a ship.
- Garboard strake.** The strake of bottom shell plating adjacent to the keel plate.
- Gas metal arc welding.** A process that welds by heating with an electric arc between a continuous consumable electrode wire and the work. Shielding is usually by an inert gas. Also called MIG (metal inert gas) welding.
- Gas tungsten arc welding.** A process, common for aluminum or stainless steel, that welds by heating with an electric arc between an electrode and the work. Shielding is obtained from an inert gas or gas mixture. Also called TIG (tungsten inert gas) welding.
- Girder.** A large strengthening member to support horizontal or vertical loads. It is larger than a longitudinal or stiffener.
- Girth.** Any expanded length, such as the length of a frame from gunwale to gunwale.
- Gooseneck, or pacific iron.** A swivel fitting on the end of a boom for connecting it to the mast or mast table. It permits the boom to rotate laterally and to be peaked to any angle.
- Gouging.** The forming of a groove or bevel by material removal; usually done with arc-air or pneumatic tools and often used for removing defective welds; also called chipping.
- Grommet.** A soft ring under a nut or bolt head to maintain watertightness.
- Ground tackle.** A general term for anchors, cables, wire ropes, etc., used in anchoring a ship to the bottom.
- Group technology.** The logical arrangement and sequence of all facets of company operation in order to bring the benefits of mass production to high variety, mixed quantity production.
- Gudgeon.** Bosses or lugs on the sternpost drilled for the pins (pintles) on which the rudder hinges.
- Gunwale.** The junction of deck and shell at the top of the sheer strake.

Gunwale bar *See* Stringer bar.

Gusset plate A bracket plate lying in the horizontal or nearly horizontal plane.

Habitability Pertaining to those spaces and systems used to provide living accommodations for the crew and passengers aboard a ship.

Halyard Light lines used in hoisting signals, flags, etc

Hatch beam A portable beam across a hatch to support hatch covers

Hatchway An opening in a deck through which cargo and stores are loaded or unloaded

Hawsepipe Tube through which anchor chain is led overboard from the windlass wildcat on deck through the ship's side. Stockless anchors are usually stowed in the hawsepipe.

Heel The corner of an angle, bulb angle, or channel; commonly used in reference to the molded line

Hold The large space below deck for the stowage of cargo; the lowermost cargo compartment

Holding piece A device used to hold metal in place for tack welding

Horning A method of checking the layout accuracy of a square or rectangular plate by matching diagonal measurements

Hot tack A tack weld followed by a hammer blow to bring the surfaces of the members in line while the weld material is still plastic

Hull The structural body of a ship, including shell plating, framing, decks, bulkheads, etc.; also the outfit specialty design group dealing with all areas of the ship except machinery and superstructure

Hull block construction method A shipbuilding system wherein hull parts, subassemblies, and blocks are manufactured in accordance with the principles of group technology.

I-beam A structural shape with a cross section resembling the letter I

Ice-strengthening Special strengthening for ice class ships as specified by a classification society

Impressed current system A cathodic protection system to slow marine corrosion of a ship's hull

Inner bottom Plating forming the top of the double bottom; also called tank top

Intercostal Made of separate parts, running between floors, frames, or beams; the opposite of continuous

Intermittent A weld where the continuity of the weld is broken by recurring unwelded spaces

Jack staff A flagstaff at the bow

Jig A device, often with metal surfaces, used as a tool or template

Joinery Work involving lightweight metallic and non-metallic materials, such as for bulkheads and ceilings in accommodation spaces

Keel The principal fore-and-aft component of a ship's framing, located along the centerline at the bottom and connected to the stem and stern frames. Floors or bottom transverses are attached to the keel

Keel blocks Heavy wood or concrete blocks on which a ship rests during construction or drydocking

Keelson side Fore-and-aft vertical plate member located above the bottom shell on each side of the center vertical keel and some distance therefrom

King post A strong vertical post used instead of a mast to support a boom and rigging to form a derrick; also called Samson post

Knee or beam knee A bracket between a deck beam and frame

Knuckle An abrupt change in direction of the plating, frames, decks, or other structure of the ship

Labor turnover The number of separations divided by average employment during a specified time interval multiplied by 100 (the number of separations during the period per 100 employees) Annual turnover rate is the monthly turnover multiplied by 12

Land To set in place an outfit unit, subassembly, or block during ship erection

Lap A joint in which one part overlaps the other

Launching To set a ship afloat for the first time

Laydown A schedule or diagram showing the individual sheets that make up a plate assembly with weight, size, drawing number, etc

Laying off The development of the lines of ship's form on the mold loft floor and making templates therefrom; also called laying down

Layout The process of making a plate assembly showing the location of longitudinals, frames, edges, and attached parts

Learning function or startup curves Mathematical formulas used for a variety of operating management purposes, especially in the areas of cost planning and control. Learning curves measure actual or planned efficiency gains for successive items produced using a repetitive process. Also called experience or progress function

- Lifeboat** A boat carried by a ship for use in emergency
- Life raft** A very buoyant raft, usually of inflatable material, designed to hold people abandoning ship
- Lightening hole** A hole cut in a nonwatertight structural member for ventilation, accessibility and/or weight reduction
- Limber hole** A small hole or slot in a frame or plate for the purpose of preventing water or oil from collecting; a drain hole
- Line heating** The use of systematic heating and cooling to shape or form steel or aluminum plates or structural shapes
- Liner** A flat or tapered strip placed under a plate or shape to bring it in line with another part that it overlaps; a filler
- Line shafting** Sections of the main shafting located in the shaft tunnel between the engine room and the afterpeak bulkhead
- Liquefied gas carrier (LNG)** A ship specially designed to carry gases, primarily natural gas, at extremely low temperatures in the liquid state. The liquid gases are carried in specially constructed tanks and considerable insulation has to be provided to ensure that the temperatures are maintained in the tanks while the main hull structure is maintained at ambient temperature
- Loftwork** The laying off of full form details at full size in preparation for cutting plate and structural members. The process is now almost entirely computerized.
- Longitudinal** A fore-and-aft structural shape or plate member attached to the underside of decks or flats, or to the inner bottom, or on the inboard side of the shell plating
- Machinery** All spaces on a ship that primarily contain operating equipment such as main propulsion machinery, auxiliary machinery, pumping systems, heating, ventilation, and air conditioning machinery, etc.; also the outfit speciality design group dealing with machinery spaces
- Manhole** A hole cut in an oil or watertight bulkhead for accessibility; associated with a cover, gasket, and means to make tight
- Manning** The number of workers or equivalent workers assigned to a particular ship (ship manning), program (program manning), or shipyard (yard manning)
- Margin angle** The angle connecting the margin plate to the shell
- Margin bracket** A bracket connecting a side frame to the margin plate at the bilge; sometimes called bilge bracket
- Margin plate** The outboard strake of the inner bottom. When the margin plate is turned down at the bilge it forms the outboard boundary of the double bottom, connecting the inner bottom to the shell plating at the bilge.
- Mast** A tall vertical or raked structure, usually of circular section, located on the centerline of a ship and used to carry navigation lights, radio antennae, and sometimes cargo booms
- Mast step** The foundation on which a mast is erected
- Mast table** *See* Boom table
- Material control** The functions of purchasing, expediting, warehousing, palletizing, and delivering material to the work site
- Material list by system (MLS)** A list of all materials required for construction of a shipboard outfit system
- Material list for component (MLC)** A list of materials for manufacturing outfit components other than pipe
- Material list for fitting (MLF)** A material list of all outfit components required by pallet
- Material list for pipe (MLP)** A list of materials for manufacturing pipe pieces
- Messroom** Dining room for ship's officers or crew
- Molded dimensions** The dimensions of the ship measured inside the shell and deck plating, horizontally to the outer edges of the frames, vertically from the baseline to the level of the tops of the beams at the ship's side
- Mold loft** Originally a large floor space used for laying down (laying off) the full size lines of a ship and for making templates to lay out the hull structural components. In modern shipyards the computer facilities which replaced the manual methods are still referred to as the mold loft
- Mooring** Securing a ship at a dock or elsewhere by several lines or cables so as to limit its movement
- Mooring ring** A round or oval casting inserted in the bulwark plating through which the mooring lines, or hawsers, are passed
- Nonwatertight** A joint or attachment that, while structurally strong, makes no effort to seal the flow of liquids from one side to the other
- Notch** Any structural discontinuity or any abrupt change in geometry, such as square cut corners of hatchways

Nozzle An enclosure around a propeller used to increase thrust at low speeds and high slip; most common on tugs and trawlers

Numerical control Numerical control implies control of a machine by means of a programmed tape or computer file on which are recorded the data needed to permit the machine to automatically perform a task. Most commonly used to control the cutting of shell parts

Oilstop A special weld to prevent leaking along the web of a continuous member from one tank to another; not required where a beveled full penetration weld is used; sometimes called waterstop.

Oil tanker A vessel specifically designed for the carriage of oil cargo in bulk

Outfit All the parts of a ship that are not structural in nature. It includes items such as pipes, derricks, masts, rigging, engines, machinery, electrical cable, hotel services, etc.

Padeye A fitting having one or more eyes integral with a base to provide a means of securing blocking, wire rope, or fiber line

Pallet A portable platform upon which materials are stacked for storage or transportation; also in zone outfitting a definite increment of work with allocated resources (information, labor, and materials) needed to produce a defined interim product

Panel A section of a ship consisting of one or more plates with associated strengthening members; also called a subassembly or block

Panting frames The frames in the forward and after portions of the hull to prevent dishing of the shell plating

Parts Refers to all the steel components that are welded to a plate assembly, including stiffeners, longitudinals, frames, girders, web frames, headers, etc

Passenger ship A ship designed mainly to carry passengers

Pillar A vertical member or column giving support to a deck girder, flat, or similar structure; also called a stanchion

Pin jig A jig consisting of a grid of adjustable pins (screw jacks) used as a building position for curved blocks or a template for curved plates

Pintles The pins or bolts that hinge the rudder to the gudgeons on the sternpost or rudder post

Pipe piece family manufacturing The classification of pipe pieces into groups having design or manufacturing attributes which are sufficiently similar to make batch manufacturing practical

Pitch or pitching A method of laying out two plate assemblies so that they can be correctly drawn together and welded at a later point in the manufacturing cycle

Planking Wood covering for decks, etc

Planning The listing of all jobs that must be performed in order to complete a project

Platen A flat, level structure upon which subassemblies, blocks, and/or outfit units are built

Plates on the round The term used to denote two or three curved plates welded together to form a cylindrical section

Platform A partial deck, usually flat; also called a flat

Poop A superstructure fitted at the after end of the upper deck

Port, cargo An opening in the side plating provided with a watertight cover or door and used for loading and unloading cargo

Porthole A hinged glass window, generally circular, in the ship's side or deckhouse, for light and ventilation; also called portlight, air port, or side scuttle

Problem area A division of the shipbuilding process into repeatable, similar work processes

Process lane A work center specifically designed to efficiently perform a certain type of work or a certain series of work steps

Production control The monitoring of the difference between actual and scheduled performance of a project

Propeller A revolving screwlike device that drives the ship through the water, consisting of two or more blades; sometimes called a screw or wheel

Propeller bossing or boss *See* Bossing or boss

Propeller post *See* Stern frame

Propeller shaft The short aftermost section of the main shafting to which the propeller is attached; also called tailshaft

Quality assurance The system used to verify that a finished product satisfactorily meets any of a set of contractually agreed upon requirements

Quarters Living or sleeping rooms

Rabbet A groove, depression, or offset in a member into which the end or edge of another member is fitted, generally so that the two surfaces are flush. A rabbet in the stern or stern frame would take the ends or edges of the shell plating, resulting in a flush surface

Rail The rounded member at the upper edge of the bulwark; the horizontal pipes or chains forming

- a fencelike railing fitted inside of a bulwark
- Rake** A term applied to the fore-and-aft inclination from the vertical of a mast, smokestack, sternpost, etc
- Reverse polarity** Direct current arc welding in which the electrode has positive polarity and ground is negative
- Resistance welding** A welding method in which the parts to be joined are clamped together and an electric current (AC) is passed through the joint. The resistance to the passage of current across the joint creates heat, thus causing the metal to melt with resulting fusion. Spot welding is a form of resistance welding.
- Ribband** A fore-and-aft wooden batten used to align the transverse frames and keep them in fair line; also a layer of insulation on the boundaries of a deck in way of insulated areas
- Rider plate** A continuous flat plate attached to the top or bottom of a girder
- Rigging** Wire ropes, fiber line, tackle, etc., used to support masts, spars, booms, etc., and for handling and placing cargo on board ship.
- Roll** To impart curvature to a plate
- Root** The smallest dimension of a joint prepared for welding; also the first pass of a weld requiring more than one pass. It may be a point, a line, or root face. Also called nose or land.
- Rudder** A device used to steer a ship. The most common type consists of a vertical metal area hinged at the forward edge to the stern post or rudderpost.
- Rudderpost** *See* Stern post.
- Rudderstock** A vertical shaft that connects the rudder to the steering gear
- Rudder stop** A lug on the stern frame or a stout bracket on deck at each side of the quadrant, to limit the swing of the rudder to approximately 37° port or starboard. A rudder angle of 35° is the maximum usually used at sea
- Samson post** *See* King post
- Scaffolding** *See* Staging
- Scantlings** The dimensions of a ship's structural members, such as frames, girders, and plating
- Scarf** A connection made between two pieces by tapering their ends so that they fit together in a joint of the same breadth and depth as the pieces connected. It is used on bar keels, stem and stern frames, and other parts
- Scheduling** The laying out of the actual time order in which jobs are to be performed in order to complete a project
- Scupper** A drain from deck to carry off accumulations of rainwater, condensation, or seawater
- Scuppers** are located in the gutters or waterways, on open decks, and in corners of enclosed decks, and connect to pipes, usually leading overboard.
- Scuttle** A small circular or oval opening fitted in decks to provide access. When used for escape and fitted with a means whereby the covers can be opened quickly to permit exit, they are called quick-acting
- Sea chest** An opening for supplying seawater to condensers, pumps, etc., and for discharging water from the ship's water systems to the sea. It is a cast or built-up structure located in the hull below the waterline, having means for the attachment of the associated piping. A suction sea chest is fitted with strainers or gratings, and sometimes has a lip that forces water into the sea chest when the ship is underway
- Seam** A fore-and-aft joint of shell plating, deck and tank top plating, or a lengthwise edge joint of any plating
- Seam line** Symbol for a welded butt joint; also called erection butt.
- Seam strap** A strap of plate serving as a connecting strap between the butted edges of plating. Strap connections at the ends of plates are called butt straps
- Sea weld** A weld all around structures exposed to the weather or in ballast tanks, potable water tanks, cargo oil tanks, and fresh water tanks welded so water cannot get under the part
- Shaft tunnel or shaft alley** A watertight enclosure for the propeller shafting, large enough to walk in, extending aft from the engine room to provide access and protection to the shafting
- Shape** A rolled bar of constant cross section such as an angle, bulb angle, channel, etc.; also to impart curvature to a plate or other member
- Sheer strake** The course of shell plating at the strength deck level
- Shell** The outer skin plates of a ship, including bottom shell and side shell.
- Shell landings** Points on the frames where the edges of shell plates are located
- Shell plating** The plates forming the outer side and bottom skin of the hull.
- Shielded metal arc welding** A process that welds by heat from an electric arc between a covered metal electrode and the work. Shielding comes from decomposition of the electrode covering. The filler metal is obtained from the electrode. Also called stick welding
- Shift of butts** The arrangement of the butts in

- structural plating members whereby the butts of adjacent members are located a specific distance from one another
- Shop** A covered floor space (a building) where work is performed in a protected area.
- Shore** A brace or prop used for support during the building of a ship.
- Shroud** One of the principal members of the standing rigging, consisting of wire rope which extends from the masthead to the ship's side, affording lateral support for a mast.
- Sight edge** The visible edge of shell plating as seen from outside the hull.
- Skids** A skeleton framework used to hold structural assemblies above ground to facilitate welding.
- Skip burn** A partially burned opening to indicate to a burner where to start an opening from the far side.
- Skylight** A framework fitted over a deck opening and having covers with glass inserted for the admission of light and air to the compartment below.
- Smokestack** *See* Funnel
- Smooth side** On a plate assembly the surface opposite the one with the longitudinals or stiffeners
- Snipe** A 45° beveled off corner
- Sounding pipe** A pipe leading to the bottom of an oil or water tank, used to guide a sounding tape or jointed rod when measuring the depth of liquid in the tank; also called a sounding tube
- Spectacle frame** A large casting extending outboard from the main hull and furnishing support for the ends of the propeller shafts in a multiscrew ship. The shell plating (bossing) encloses the shafts and is attached at its after end to the spectacle frame used in place of shaft struts.
- Spring bearing** Bearings to support line shafting
- Stage** A classification of work based on when it will be performed (in what sequence) during the construction process relative to other work.
- Staging** Temporary or movable wooden or metal structures for supporting workmen, tools, and materials; also called scaffolding.
- Stanchion** A vertical column supporting decks, flats, girders, etc.; also called a pillar. Rail stanchions are vertical metal columns on which fencelike rails are mounted. *See also* Rail
- Standing rigging** Fixed rigging supporting the masts such as shrouds and stays. Does not include running rigging such as boom topping lifts, vang, and cargo falls
- Stays** Fixed wire ropes leading forward from aloft on a mast to the deck to prevent the mast from bending fore or aft.
- Stealer** A single wide plate that is butt-connected to two narrow plates, usually near the ends of a ship.
- Steering gear** A term applied to the steering wheels, leads, steering engine, and fittings by which the rudder is turned.
- Stem** The bow frame forming the apex of the intersection of the forward sides of a ship. It is rigidly connected at its lower end to the keel and may be a heavy flat bar or of rounded plate construction.
- Stern** After end of a ship.
- Stern frame** Large casting, forging, or weldment attached to the after end of the keel. Incorporates the rudder gudgeons and in single-screw ships includes the propeller post.
- Stern post** The vertical part of the stern frame to which the rudder is attached.
- Stern tube** The watertight tube enclosing and supporting the propeller shaft. It consists of a cast iron or cast steel cylinder fitted with a bearing surface upon which the propeller shaft, enclosed in a sleeve, rotates.
- Stiffener** A structural section (usually angles, tees, or I-beams) attached to a plate to strengthen it.
- Strake** A course or row of shell, deck, bulkhead, or other plating.
- Stringer** A fore-and-aft girder running along the side of a ship at the shell; the outboard strake of plating on any deck; also the side pieces of a ladder or staircase into which the treads and risers are fastened.
- Stringer bar** The angle connecting the deck plating to the shell plating or to the inside of the frame. The strength deck stringer bar is usually called the gunwale bar.
- Stringer plate** *See* Deck stringer.
- Strut** An outboard columnlike support or vee-arranged support for the propeller shaft; mostly used on warships with more than one propeller, instead of bossings; rarely used on modern merchant vessels.
- Subassembly** An assembly of parts (primarily structural parts). Subassemblies, when joined together, form blocks.
- Superstructure** A decked-over structure above the upper deck, the outboard sides of which are formed by the shell plating, as distinguished from a deckhouse that does not extend outboard.

- to the ship's sides
- Supervisor of Ships** An organization within the Naval Sea Systems Command responsible for developing repair specifications and managing shipbuilding and repair contracts between the Navy and private industry
- Surface preparation** The work required to permit coating materials (primarily paint) to be satisfactorily applied to metals
- System** A structurally or operationally functioning product
- Tabernacle** An arrangement of brackets used to support a mast
- Tack weld** A weld made to hold parts of a weldment in proper alignment until final welds are made
- Tailshaft** *See* Propeller shaft
- Tank, ballast** *See* Ballast tank
- Tank, peak** *See* Afterpeak, Forepeak
- Tank, settling** Fuel oil tanks used for separating entrained water from oil
- Tank, trimming** A tank located near the ends of a ship. Seawater (or fuel oil) is carried in such tanks as necessary to change trim
- Tank, wing** Tanks located well outboard adjacent to the side shell plating, often consisting of a continuation of the double bottom up the sides to a deck or flat
- Tank top** *See* Inner bottom
- Telegraph** An apparatus, either electrical or mechanical, for transmitting orders, as from a ship's bridge to the engine room, steering gear room, or elsewhere around the ship
- Telemotor** A device for operating the control valves of the steering engine from the pilothouse, either by fluid pressure, or by electricity
- Template** Wood, paper, or steel full-size patterns to be placed on materials to indicate the size and location of penetrations, plate edges, etc.; also to indicate the curvature to which plate, frames, etc., are to be bent
- Test head** The head or height of the column of water which will give a prescribed pressure on the vertical or horizontal sides of a compartment or tank in order to test its tightness or strength
- Thrust recess** A small compartment at the after end of the main engine room at the forward end of shaft tunnel, designed to contain and give access to the thrust shaft and block
- Tie plates** Plates used to tie parts of the structure together when they are not otherwise directly connected to each other
- Tiller** An arm attached to the rudder stock which turns the rudder
- Topping lift** A wire rope or tackle extending from the head of a boom to a mast, or to the ship's structure, for the purpose of supporting the weight of the boom and its loads, and permitting the boom to be raised or lowered
- Topside** Portion of a ship accessible for repair work while the ship remains afloat
- Transverse** At right angles to the fore and aft centerline
- Tripping bracket** Flat bars or plates fitted at various points on girders, stiffeners, or beams as reinforcement to prevent the free flanges from tripping
- Trunk** A vertical or inclined space or passage formed by bulkheads or casings, extending one or more deck heights, around openings in the decks, through which access can be obtained and cargo, stores, etc., handled, or ventilation provided without disturbing or interfering with the contents or arrangements of the adjoining spaces
- Trunk, escape** A vertical trunk fitted with a ladder to permit personnel to escape if trapped. Usually provided from the after end of the shaft tunnel to topside spaces
- 'Tween decks** The space between any two adjacent decks
- Unit** A self-contained, self-supporting collection of outfit pieces assembled prior to combining with structural blocks or to landing on board during erection; also called outfit unit
- Uptake** A metal casing that carries smoke and hot gases from a boiler or engine to the smokestack
- Vang** Wire rope or tackle secured to the end of a cargo boom, the lower end being secured to the deck, top of bulwark, or to a special post at the ship's side. Used to swing the boom and hold it in a desired position
- Ventilator cowl** A hood-shaped top or end of a natural ventilation trunk that may be rotated to cause wind to blow air into or out of the trunk
- Waterstop** *See* Oilstop
- Waterway** A narrow gutter along the edge of the deck for drainage
- Web** The main part of a bent or flanged plate or structural section
- Web frame** A built up frame to provide extra

strength. Usually fabricated of a web plate flanged or otherwise stiffened and spaced several frames apart, with the smaller frames in between.

Weld preparation. A contour such as a bevel, placed on the edge of a member or plate to facilitate welding.

Well. The space in the bottom of a ship to which bilge water drains so that it may be pumped overboard; also the space between partial superstructures.

Wildcat. A special type of coglike windlass drum whose faces are formed to fit the links of an anchor chain. The rotating wildcat causes the chain to be slacked off when lowering the anchor, or hauled in when raising it.

Winch. A machine, usually steam or electric, used primarily for hoisting and lowering cargo but also for other similar purposes.

Windlass. The machine used to hoist and lower anchors.

Work breakdown structure. Any classification system for subdividing the work required for a ship construction or conversion program in order to manage the program. Categories may be defined according to functional systems or interim products.

Work measurement. An analysis technique designed to establish the time an average qualified worker should take to carry out a specified job at a defined level of performance.

Work package. A resource subdivision which specifies the material and/or labor required to complete some portion of a shipbuilding or repair contract. A work package should correspond to the work breakdown structure in use and may be either system or product oriented.

Zone. A geographical sub-section of a ship that includes all items within the boundaries of the physical region.

Zone outfitting method. A shipbuilding system which organizes outfitting work by zone and stage into on-unit, on-block, and on-board work.

Zone painting method. A shipbuilding system which integrates surface preparation and coating work into the overall construction process.

Zone technology. Management methodology based on organizing work by zone rather than by system.

INDEX

A

- Accommodations, 142
 - Accuracy, 319
 - Accuracy control, 319-58
 - applications, 349-58
 - block assembly, 339, 355
 - control items, 344-49
 - cycle, 327
 - defined, 319
 - design, 349
 - evaluating, 340-49
 - execution, 335-40
 - hull erection, 339-40
 - information flow, 341
 - mold loft, 349-53
 - parts fabrication, 337, 353
 - plan, 240
 - planning, 326-35
 - role, 327
 - stage measurements, 330
 - standardization, 332-35, 355
 - statistical analysis, 319; principles of, 319-24
 - subassembly, 337-39, 353-55
 - urgent analysis, 343-44
 - work standards, 333-35
 - Accuracy control check and report sheet, 290, 291
 - Accuracy standard, 335, 383-84
 - construction stage, 335
 - range, 335
 - setting, 342
 - tolerance limit, 335
 - Acquisition policy, 28
 - Activity duration, 257
 - Addition of variance theorem, 324
 - Adjustment cost, 37, 41-43
 - external, 37
 - internal, 37
 - Advanced Industrial Management, 383
 - Agreement for Boat Repair (ABR), 366
 - Administration, 8
 - Air conditioning, 140-41
 - equipment mechanic, 11
 - Air test plan, 289
 - Alpha iron, 108-9
 - Aluminum, 112-16
 - alloy, 112-16
 - welding, 116
 - American Bureau of Shipping, 13
 - structural steels, 112
 - Analysis sequence, 343
 - Anchor, 14
 - Arc welding
 - flux-shielded, 125-26
 - gas-shielded, 125-26, 183
 - Assembly, 55
 - Assembly line, 5
 - Assembly sequence, alternate, excess
 - distribution, 357
 - Austenitic steel, 110
 - Autokon, 246
 - Auto-welding, planning, 287-88
- ## B
- Bainite, 110
 - Baseline, 334
 - Batch, lot size, 48
 - Batch flow, conventional vs. group process, 46-47
 - Bending, pipe, 139-40
 - Bidding, 4
 - competitive, 4
 - Blaster, 11
 - Blasting, 179-81
 - Block
 - curved, 74, 191-92
 - definition, 68, 277, 283-87; basic, 283-84; final, 215; flat, 74, 191
 - planning, 261
 - pre-definition, 261, 280; considerations, 280-83; general arrangement, 282-83; midship section, 281-82
 - size, 68
 - superstructure, 192
 - surface preparation, 180
 - Block arrangement handbook, 290

- Block assembly, 70-74
 - accuracy control, 339, 355
 - block storing, 296-97
 - guidance plan, 289
 - master schedule, 336
 - material control, 297
 - planning, 261; preliminary, 201-2
 - problem area, 74
 - process, efficiency, 202-3
 - productivity, 297-98, 298-302
 - scheduling, 296
 - stage, 74
 - stage classifications, 74
- Block storage
 - block assembly, 296-97
 - plan, 291
- Boiler works, 169-70
- Bottleneck, 40-41, 44
- Brazing, 134-35
- Bridge crane, 144-45, 174
 - top running, 145
 - under running, 145
- Britships, 246
- Budget, 32
- Budget control list, 201, 268-70
 - functions, 268-69
 - material lists by system, 264-70
- Budget control work volume, 281
- Building position, 171-73
- Building strategy, 201, 253
 - contract requirements, 254
 - outputs, 253, 254
 - production phases, 254
 - work classification, 254
- Building way, longitudinal sloped, 171
- Bulk carrier, 9, 168
- Bureau Veritas, 13
- Burning torch, 118
- Butt weld, 123
- Buy in, 38
- C
- Cable, 186
- Cabotage, 14, 22
- Capital Construction Fund, 22
- Capital expenditure, 28
- Capital intensiveness, flexibility, 175
- Capital stock, 35
- Carbon, 107-8
- Carpenter, 12
- Cash flow, 26
- Cellular manufacture, 46-47
- Cementite, 109
- Central limit theorem, 321
- Centrifugal blasting, 152-53
 - advantages, 153
 - airless, 153
- Centrifugal flagellater, 155
- Chainfall, 184
- Change
 - design, 240-44
 - key plan, 242
- Charpy V-notch test, 110
- Checking procedure, 334
- Check sheet, 337, 338
- Chipper/grinder, 12
- Classification
 - by use, 13-14
 - material, 305-14
 - product aspects, 55
 - scope, 50-51
- Classification society, 13-14
 - annual survey, 13-14
 - areas covered, 13-14
- Clip and bolt, 185
- Coaming unit, 87
- Coating
 - flame-sprayed, 157-58
 - systems, 156-57
- Coding, 51
 - defined, 51
- Combatant, 11
 - nuclear, 29
- Combatant ship, 143
- Combat system, 142-43
- Come-along, 184
- Communication, 239
 - feedback channels, 277
 - hull construction, 276-78
- Component
 - block joint, 237
 - side by side alignment, 236
 - standard, 308, 312
- Component procurement, 84
- Component supplier, 24-25
- Composite arrangement, 216-18, 265, 266
 - considerations, 217
 - engine room, 215, 217
 - hull outfit, 218
 - marked, 220; supplements, 220
 - objectives, 216-17
 - outfitting type separation, 217
 - zone-by-zone, 218
- Composite draft, 215-16
 - considerations, 216
 - contiguous pallet, 216
 - engine room, 215, 216
 - rough, 216
- Compression, 44
- Computer, 29
 - applications, 244
 - history, 244
- Computer-aided design
 - advanced integrated, 246
 - hardware, 245-46
 - integrated system, 245
 - key plan, 249
 - network, 250
 - outputs, 246-47
 - potential, 247-48

- process, 246
 - schedule review, 249
 - software, 245-46
 - work instruction, 248
 - Computer-aided manufacturing
 - advanced integrated, 246
 - hardware, 245-46
 - integrated system, 245
 - material control, 245
 - M/C instructions, 244-45
 - network, 250
 - potential, 247-48
 - process, 246
 - process planning, 244
 - purchasing, 244-45
 - robot, 244, 246
 - software, 245-46
 - Computer algorithm management information system, 256
 - Computer-integrated manufacturing, 244
 - Conglomerate merger, 26
 - Conservatism, 28
 - Construction, 4-5
 - manufacturing levels, 4
 - parts manufacturing, 4
 - Construction rate, optimum, 33
 - Construction Reserve Fund, 23
 - Construction schedule, 40
 - Construction stage, accuracy standard, 335
 - Construction time, optimum, 33
 - Constructive change, 38
 - Container, 147-48
 - Containership, 9
 - Contract, 4
 - cost, 4
 - delivery date, 4
 - performance requirements, 4
 - Contract drawing, 280
 - Contract management, 8
 - Contract negotiation, 260
 - Contract plan, 197, 200
 - Control by lot, 94-95
 - Control chart, 321-23
 - Shewhart, 321
 - Control item, 336
 - Controlling, 66-67
 - Conversion
 - aggregate schedule, 375, 376, 377
 - commercial, 362-64
 - critical path, 371
 - network, 371-72, 382
 - personnel, 398, 403
 - planning, 366-84
 - planning documents, 375, 376, 377
 - product-oriented, 375-82
 - product work breakdown structure, 371, 373
 - scheduling, 371, 372
 - systems-oriented, 371-72
 - vs. new construction, 373, 396-98
 - virtual flow lane, 373
 - zone-oriented, 372-75
 - Convexity, 37
 - Conveyor, 143-44
 - pipe, 144
 - roller and chain, 144
 - Conveyor system, 174
 - Corporate plan
 - five-year, 257-58
 - management, 258
 - Corrosion, 150
 - factors, 151
 - resistance, 111-12
 - Cost
 - adjustment, 37, 41-43
 - final, 38
 - fixed, 33
 - government regulation, 25
 - group technology, 53
 - hardcore, 39
 - indirect collection, 67
 - labor, foreign, 28; U.S., 28
 - measurement, 45
 - Cost center, 300
 - Cost curve, 39
 - labor quality, 40
 - Costing, 67
 - zone-oriented, 67
 - Cradle, 171
 - Craftsman, 5
 - Crane, 144-46, 163
 - magnetic clamp, 145
 - mobile, 146
 - Critical path, 255
 - conversion, 377
 - material, 307
 - overhaul, 371
 - repair, 371
 - Critical Path Method (CPM), 253-55
 - Crystal lattice structure, 106-7
 - Cumulative output, 41
 - Curved block, 74, 191
 - Customer requirements, 3
 - Cutting, 117, 205, 208
 - gas, 118
 - mechanical, 117
 - plasma arc, 119
 - thermal, 118-20
 - Cyclical, labor market, 25
- ## D
- Deck cleaning unit, self-propelled, 154
 - Deck fitting, 142
 - Defense industry, 27
 - Defined item, 217
 - Deformation, 353
 - Delivery certificate, 160
 - Delivery date, 43
 - Delta iron, 108
 - Dendrite, 107

- Dendritic crystal growth, 107
 - grain boundaries, 107
 - Design
 - accuracy control, 349
 - basic, 195, 197, 200; objectives, 201-2; procurement specifications, 202; production people, 261; regulatory body review, 205; stages, 200-203
 - change, 240-44; causes, 240, 242; counter-measures, 242-44; preventing, 242
 - concept, 195
 - contract, 3, 195
 - coordination, material definition, 220
 - defined, 222
 - detail, 4, 195
 - development by zones, 232-34; scheduling, 232
 - engineering, 222-44
 - functional, 62, 195, 197, 203-13; key plan, 203-7; material list by system, 207-13; naval architectural calculation, 207; objectives, 203-7; system diagrammatic, 207
 - group technology, 199-200; additional factors, 199; characteristics, 199
 - logic, 229-40
 - material, 303-6
 - material list, 314
 - overlapping stages, 238-40; communication, 239; hull structural key plans, 239; vendor drawings, 239
 - planning, 4
 - preliminary 3, 195
 - principles, 227-28
 - process, 62-63, 64; product-oriented, 195, 196
 - production, 222-44
 - scheduling, 4, 261-67; objectives, 262; sequence, 263
 - ship mission, 3
 - transition, 62-63, 195, 197, 213-17; by zone, 213; pallet concept, 213; responsibilities, 213, 215
 - U.S. Navy, 3
 - work instruction, 195, 197, 218-22; mold loft, 222; responsibilities, 219, 220
 - zone orientation, 231-32
 - Design agent, 3
 - Design approach, improved, 228
 - Design cycle, 195-97, 199
 - Go meeting to K meeting, 203
 - ML meeting to keel laying, 204
 - Design department master schedule, 263, 264
 - Designer
 - hull structural, 213
 - outfit specialty, 213
 - Design group master schedule, 263-64
 - Design instability, 44
 - Design model, 248-50
 - advantages, 248-50
 - Design module, 313
 - Design outfit specialty group, 63, 64
 - Design personnel schedule, 267, 268
 - Design stage, 200-222
 - Destroyer, 164
 - Detail design, 62-63
 - Detail work instruction
 - planning, 284-93
 - scheduling, 284-93
 - Det Norske Veritas, 14
 - Diagrammatic, 264, 265
 - Diesel engine/foundry works, 169
 - Disc sander, 155
 - Distortion
 - removal, 135-36, 137; line heating, 135-36; welding induced, 356
 - Distribution, modifying, 343
 - Dock, 165-66, 171-73
 - caisson end, 172
 - dry dock, 172-73; removable wing wall, 173
 - guillotine gate, 172
 - launch pontoon, 173
 - Dock trial, 159
 - Dog, step cut, 184
 - Drawing issue schedule, 266-67
 - Dry dock, 172-73
 - removable wing wall, 173
 - Dual grouping, 61
 - Duct work, sheet metal, 140-41
 - Dynamic model, 33
- E
- Economic model, 31-45
 - Economy of scale, 36
 - Edge preparation, 176
 - Egg-box assembly, 177-78
 - Electrical assembly
 - manpower expenditure, 299
 - productivity, 298, 301
 - Electrical installation, 141-42
 - Electric arc welding, 126, 129-33
 - American Society for Testing and Materials, 130
 - American Welding Society, 130
 - electrode, 124
 - flux-shielded, 129-30
 - gas-shielded, 132-33
 - manual-shielded, 130
 - Electric cable assembly, manpower expenditure, 299
 - Electrician, 12
 - Electric resistance welding, 126, 129
 - Electrogas welding, 126, 133, 134
 - Electron beam welding, 126, 133-34
 - Electronics mechanic, 12
 - Electroplater, 12
 - Electroslag welding, 126, 133-34
 - Employment
 - stability, 23-24

- End product tolerance, 324
 - Engineered labor standard, 257
 - Engineering, 8
 - defined, 222
 - design, 222-44
 - group technology, 199-200
 - Engineering cycle, 202
 - Go meeting to K meeting, 203
 - ML meeting to keel laying, 204
 - Engine room
 - composite arrangement, 215, 217
 - outfit unit, 87
 - Equivalent ton, 32
 - Erection, 4
 - productivity, 297-98, 301
 - sequence, 207
 - Erection check schedule, 336
 - Erection schedule, 279
 - Erection shop, scheduling, 298
 - Erection site painting, 181
 - Error, 320
 - defined, 320
 - Estimate, initial, 38
 - Estimating, 253
 - Evaluation, accuracy control, 340-49
 - Excess, 325, 334
 - distribution, 357
 - Excess standard, 356
 - Excess vs assembly sequence, distribution, 356
 - Experience curve, 36-37
 - Experience level, 35
- F
- Fabrication, 54
 - Facilities, 55
 - Facility plan, long-range, 259
 - Fairing, 135-36, 166
 - classification, 139
 - Family, 46
 - Family manufacturing, 46, 60
 - Fatigue strength, 111
 - Fatigue test, S-N plot, 111
 - Federal government, 14
 - Ferrite, 109
 - Fillet welding, 123, 356
 - Finish painting, 93
 - Finish undercoat painting, 92-93
 - Fishing vessel, 10
 - Fitting drawing, 264, 265
 - Fitting instruction, 232
 - Fitting stage, 215
 - Fitting work instruction drawing, 220
 - Fixed cost, 33
 - Fixture, 187
 - Flame planer, 120
 - Flatbed truck, 146-47
 - Flat block, 74, 191, 192
 - Flexibility, 66
 - capital intensiveness, 175
 - Flow lane *See* Process lane
 - Fork lift truck, 147
 - Format standardization, 240
 - Forming, 120-23
 - mechanical, 120-21
 - thermal, 121-23
 - Fracture mechanics approach, 111
 - Frame bender, 122
 - Frigate, 164
 - Fusion welding, 123
 - heat input rate, 123-25
 - heat source intensity, 123
 - process characteristics, 126-28
 - shielding, 125-26
 - thermal cycle, 126
 - weld metal metallurgical effects, 126
- G
- Gamma iron, 108-9
 - Gantry crane, 145, 174
 - Gantt chart, 263, 264
 - Gas metal arc welding, 132-33
 - Gas-shielded arc welding, 125-26, 183
 - Gas tungsten arc, 132, 133
 - Gas welding, 128-29
 - oxyacetylene equipment, 128
 - Gaussian distribution, 326
 - Gear-pulley device, 184
 - General Dynamic Electric Boat Division, 174
 - Germanischer Lloyd, 13
 - Government regulation cost, 25
 - Grain growth, 126
 - Grand block, 94
 - Grand-block, L-type, 283, 284
 - Grand-block joining, 73, 75-81
 - problem area, 74
 - stage, 74
 - Grand-unit joining, 83-86
 - Graving dock, 166, 172
 - advantages, 172
 - disadvantages, 172
 - Gravity welding machine, 131
 - Group technology, 5, 29, 31, 45-53
 - batch size, 47
 - classification, 49-51; Boeing Company, 52
 - classification system, 46
 - coding, 51
 - company functions affected, 50
 - cost, 52-53
 - defined, 47, 48
 - design, 199-200; additional factors, 199; characteristics, 199
 - engineering, 199-200
 - engineering effort intensity, 200, 201
 - family, 46
 - interim product, 46
 - job satisfaction, 46
 - zone construction, 53

H

- Hammerhead crane, 146
- Hand tool cleaning, 154-55
- Hardcore cost, 39
- Hatch cover, 87
- Hawser, 14
- Heating, 140-41
- Hoisting machine, synchrolift, 173, 174
- Hull, 63
 - integrated schedule, 66
- Hull block, 4
- Hull block construction method, 60, 68-75
 - objectives, 68
 - planning, 68-69
 - product aspect classification, 68
 - seven levels, 68-75
- Hull bottom cleaner, 153
- Hull construction, 55
 - basic production plan, 280-81
 - basic schedule, 280-81
 - communication, 276-78
 - manpower expenditure, 299
 - on-block, 277-78
 - on-board outfitting, 279
 - planning, 271-98
 - process lane, 276
 - production planning flow, 286
 - production progress, 299
 - production scheduling flow, 287
 - schedule, 275
 - standards, 279
 - start date, 264
- Hull construction processes plan, 280-81
- Hull erection, 74
 - accuracy control, 339-40
 - problem area, 74
 - rework analysis, 344-47
 - stage, 74
- Hull erection layout plan, 280
- Hull erection master schedule network, 281
- Hull feature, outfit convenience, 237-38
- Hull material, 105-16
- Hull outfit, 63, 64
 - composite arrangement, 218
- Hull structural design, outfitting, 236-38
- Hull structural design schedule, 276
- Hydraulic device, 185
- Hydraulic jack, 185
- Hydrofoil, 11
- Hydrostatic test, piping unit, 159

I

- Idleness, 52
- Industrial project management cycle, 61, 62
- Industrial vehicle, 146-47
- Industry organization, 25-28
 - business environment, 26-27
 - capital budgeting policy, 26-27
 - economic performance, 27
 - economic value, 25

- foreign purchase, 25-26
- investment, 27
- merger, 26
- profitability, 26
- strategic value, 26
- Industry status, 14-29
 - economic model, 14-15
 - national policy, 14-15
 - political factors, 14-15
 - U.S., 18-21; U.S. shipyard locations, 19
 - U.S. market, 21-23; history, 21-23; Navy, 21-23
 - world market, 15-18
- Information booklet, title page, 227
- Information flow, 197-99
 - standards, 357-58
- Ingalls Shipbuilding, 165, 168
- Innovations, 406
- Insulator, 12
- Insurance rates, 14
- Interim product, 21, 32, 33, 34, 46, 48, 68
 - accuracy, 319
 - tolerance, 324-25
- Interstitial solid solution, 106
- Iron/iron carbide phase diagram, 108

J

- Jack, hydraulic, 185
- Jacking clamp, 185
- Japanese shipyard, 29
- Jib crane, 144-46, 183
- Jig, 188
- Job satisfaction, 46
- Joiner, 12
- Joiner work, 142
- Jones Act, 22
- Journeyman, training, 24
- Journeyman/total worker ratio, 36

K

- Kaiser, Henry, 163
- Kerf, 353
- Kerf compensation, 342
- Key plan, 207
 - change, 242
 - computer-aided design, 249
 - mold loft, 223
 - structural, 208-9

L

- Labor
 - cost; foreign, 28; minimization, 34; U.S., 28
 - learning curve, 36-37
 - market, cyclical, 25
 - quality, 35, 38, 39-40; adjusted, 35; cost curve, 39-40
 - shortage, training, 23
- Labor adjustment cost
 - external, 37-38
 - frictional, 37-38
 - internal, 37-38
- Laborer, 12

- Labor force, 23-24
- Labor hoarding, 37
- Labor intensiveness, 18
 - U S vs. foreign, 27
- Labor standard, engineered, 257
- Larson, B , 171
- Laser welding, 126, 133-34
- Launching, 171-73
 - level building facilities, 174
- Launch pontoon, 173
- Layoff, 23
- Legislation, 14
- Line heating, 121-23, 356
 - curvature, 121
 - distortion removal, 135-36
 - local reactions, 121-22
- Linnean hierarchical taxonomy, 49
- Lloyd's Register of Shipping, 13
 - quality assurance, 158
- Loading, process lane, 193-94
- Lofting, computer systems, 166
- Loftsman, 12
- Lot size batch, 48
-
- M
- Machinery, 63, 137-38
 - installation, 137-38
 - loading methods, 213
 - reliability, 14
- Machinery arrangement module, 231
- Machinery outfitting, 63, 64
 - manpower expenditure, 299
 - productivity, 299-302
- Machine shop, 138
- Machinist, 13
- Major detail, planning, 287-89
- Management cycle, industrial project, 61, 62
- Management system, 53
 - corporate plan, 258
- Man-hour, borrowing, 52
- Man-hour budget, 268, 292
- Man-hour budget determination system, 267-68, 292-93
- Man-hour control, 292-93
- Man-hour control curve, 267-68
- Man-hour expenditure, 298
- Manning level, 35, 41
- Manpower, 55
- Manpower expenditure
 - electric cable assembly, 299
 - electrical assembly, 299
 - hull construction, 299
 - machinery outfitting, 299
- Manufacturing work instruction, 198, 232
- Manufacturing work instruction drawing, 221-22
- MarAd *See* Maritime Administration
- Margin, 325
- Marinette Marine, 174
- Maritime Administration, 14, 26, 27
 - National Defense Reserve Fleet, 366
- Market, 14
- Market cycle, 23
 - early 1970s, 15-16
 - oil embargo, 15
- Marketing plan, long-range, 258
- Market research, 258
- Marking, 175-76, 177
- Martensite, 109-10
- Martensitic steel, 110
- Mass production, 5
 - technique, 5
- Master outfitting schedule, 272
- Master schedule, block erection, 336
- Master Ship Repair Agreement (MSRA), 366
- Mat unit, 87
- Match mark, 334
- Material, 24-25, 55
 - allocated, 307
 - allocated stock, 307
 - assigned geographically, 231-32
 - classification, 305-14
 - critical path, 307
 - definition, 303-5
 - design, 305-8
 - geographic arrangement, 233
 - lead times, 307
 - long-lead-time, 207, 212
 - non-standard, 213
 - procurement, 305-14
 - production, 303, 304
 - requisitioning process, 211-12
 - short-lead-time, 207
 - standard, 213, 312-13
 - stock, 307
- Material classification system, 29
- Material code
 - component code, 308
 - designating system, 308
 - number, 305
 - part code, 308
- Material control, 302-17
 - block assembly, 297
 - classification, 307-8
 - parts fabrication shop, 295
 - subassembly section, 296
- Material control group, 174-75
- Material control identification code, 307-8, 309
- Material cost classification
 - number, 305
 - structure, 310
- Material definition, 221, 303-5
 - scheduling objectives, 262
- Material handling, 143-50, 173-74
 - equipment, 143-50
 - inventory, 175
 - retrieval, 175
 - storage, 175
 - system design, 148
- Material issue, palletizing, 315, 317
- Material list, 312, 313

- Material list (*continued*)
 - design, 313-14
 - mold loft, 225, 226
 - procurement, 313-14
 - Material list by system, 197, 207-13
 - description, 212
 - Material list for components, 213
 - Material list for fitting, 197, 220-21, 232
 - Material list for manufacturing, standardization, 222
 - Material market, 24-25
 - Material ordering zone, 62, 212
 - McNeill shipyard classification system, 161
 - Mean, 320
 - Mean value analysis, 341-42
 - Measurement, 358
 - Measure of output, 32
 - Mechanical bending, 124, 135
 - Melting point, 125
 - Merchant ship, national policy, 15
 - Merged variation, 323-24, 349
 - Metal
 - atom arrangement, 106
 - compositional changes, 106
 - structure, 105-7
 - Metal alloy, 106
 - defined, 107
 - mechanical properties, 107
 - Metal inert gas welding, 132-33
 - Metallurgy, 105-7
 - Metal process, 116-36
 - Method analysis, 324
 - Midship section, 279
 - block pre-definition, 281-83
 - Milestone schedule, 272
 - Military specifications, 25
 - Mill scale, 151
 - Mobile crane, 144, 146
 - Mock, 187
 - Model engineering, 248-50
 - Modular construction, 166
 - Module
 - staging, 166
 - Molder, 13
 - Mold loft, 166, 222
 - accuracy control, 294, 349-53
 - computer capability, 222
 - error list, 354
 - frequency chart, 354
 - key plan, 223
 - material list, 225, 226
 - N/C cutting plan, 175-76
 - outputs, 222
 - pallet, 226
 - responsibilities, 222
 - schedule, 226, 294
 - work instruction, 224
 - work instruction plan, 224
 - yard plan, 223
 - Mold loft/work instruction guidance plan, 291-92
 - Monthly schedule, 273
 - Multi-pass welding, 123, 125
- N
- National policy, 18, 23
 - merchant ship, 15
 - National Shipbuilding Research Program, 28
 - Natural disaster, 38
 - Naval architectural calculation, 200-201
 - functional design, 207
 - Navy, 18
 - N/C steel marking process, flow diagram, 175-76
 - Network
 - defined, 253
 - planning, 253-55, 256
 - Newport News, 27
 - Normal distribution, 320, 321
 - mean, 320
 - sampling, 320
 - standard deviation, 320
 - Nozzle blasting, 153-54
- O
- On-block, hull construction, 277-78
 - On-block outfitting, 82, 86-88
 - goals, 86
 - pipe tunnel, 88
 - problem area, 86-87
 - stage, 86
 - On-board outfitting, 82, 88-89
 - hull construction, 278
 - problem area, 88
 - stage, 89
 - zone, 88-89
 - On-unit outfitting, 82
 - Optimum block, 68
 - Optimum output rate, 39
 - Ordinance equipment mechanic, 13
 - Outfit planning group, 375
 - Outfit process, 136-43
 - Outfit specialty group man-hour expenditure, 267-68
 - Outfitting, 55
 - advanced, 166
 - integrated schedule, 66
 - on-block, 259
 - on-board, 259
 - on-unit, 259
 - process lane, 193
 - strategy, 213, 215
 - system components, 105; small independent tanks, 237; stages, 220, 221
 - Outfitting milestone schedule, 264
 - Outfitting shop master schedule, 289
 - Outfit unit, 236
 - Outfit unit module, 231
 - Out-of-sequence work, 45
 - Output
 - changes, 44

- required, 38-39
- unit, 34
- Output rate, optimum, 39
- Overhaul
 - commercial, 302-4
 - critical path, 371
 - Navy, 382-84, 393, 394
 - network, 371-72, 382
 - personnel, 385
 - planning, 368-84
 - planning documents, 375
 - product-oriented, 375-82
 - product work breakdown structure, 371, 373
 - scheduling, 371-72
 - systems-oriented, 371-72
 - vs new construction, 373
 - virtual flow lane, 373
 - zone-oriented, 372-75
- Overlap, planning, 61
- P
- Padeye, 186
- Painter, 13
- Painting, 55, 179-81
 - erection site, 181
 - facility, 158
 - integrated schedule, 66
 - new construction, 157
- Paint system, zone painting method, 89-93
- Pallet, 82, 148
 - coding systems, 197-99
 - definition, 213-15
 - mold loft, 226
 - pipe pieces, 104
 - storage areas, 103
 - subcontractor delivery, 317
 - work breakdown, 314, 315
- Pallet concept, 197, 198
- Palletizing, 314-18
 - functional flow, 314, 316
- Pallet list, 213
 - original, 213
- Panel assembly, 176-78
- Panel line, 176-78
 - blast and coast facility, 180
 - high-capacity, 165
 - layout, 176-78
 - steel, 179
- Panel shop, layout, 176-78
- Parent/child sign, 212
- Parts assembly, 70
 - level classification, 70
 - sub-block part concept, 70
- Parts fabrication, 70
 - accuracy control, 337, 353
 - problem area, 70
 - productivity, 299-302
 - stage classifications, 70
- Parts fabrication process lanes plan, 290
- Parts fabrication shop, 180
 - material control, 295
 - productivity, 295
 - scheduling, 292-95
- Patternmaker, 13
- Pattern making, 175-76
- Pearlitic steel, 110
- Pennsylvania Shipbuilding, 180
- Percent physical completion, 34
- Personnel
 - conversion, 398-403
- Physical completion, 32
- Physical output rate, 35
- Pickling, 156
- Piece number, 305
- Pipe
 - bending, 139-40
 - conveyor, 144
 - cutting, 139
 - size, 138-39
 - storage and retrieval rack, 182
 - welding, 138-39
- Pipe bending machine, 140
- Pipe coaster, 183
- Pipe fabrication, 181-83
 - automation, 181
 - semiautomated, 181-82
- Pipe fitter, 13
- Pipe material, 138
- Pipe passage, multiple pipe runs, 234
- Pipe piece
 - assembly, 99-103
 - fabrication, 97-99
 - palletized, 140-41
- Pipe piece family manufacturing, 93-104
 - assembly, 94
 - classifications, 98, 100, 101, 102
 - coating, 103-4
 - control by lot, 94
 - determining families, 99
 - joining level, 94
 - key zone, 93
 - manufacturing levels, 95
 - material receiving, 95-97
 - palletizing, 104
 - pipe piece assembly, 99-103
 - pipe piece fabrication, 93, 94, 97-99
 - pipe piece joining, 103
 - problem area, 94
 - product aspects, 94, 95
 - testing, 103-4
 - work flow lanes, 93
 - work lot, 94-95
 - work packages, 94
- Pipe piece joining, 103
- Pipe piece manufacturing, 138
- Pipe run
 - common supports, 235
 - multiple, 234
 - parallel to XYZ axes, 235
- Pipe shop band saw, 139

- Pipe tunnel, on-block outfitting, 88
- Pipewelder, 13
- Piping, 138-40
- Piping layout module, 231
- Piping unit, 87
- Planning, 61-67
 - accuracy control, 326-35
 - autowelding, 287-88
 - basic, 279-84
 - block, 261
 - block assembly, 261
 - contract, 260-61
 - conversion, 368-84
 - cycle, 274
 - detail, accuracy control, 329-32
 - detail levels, 257, 259
 - detail work instruction, 284-93
 - elements, 61
 - general, 260
 - hull construction, 271-98
 - integration, 252-53
 - major detail, 287-89
 - network, 253-57
 - overhaul, 368-84
 - overlap, 61
 - overview, 257-71
 - precontract, 260-61
 - preliminary, accuracy control, 328-29
 - process, 57-59
 - production organization, 252
 - repair, 368-84
 - shop-level, 293-94
 - work flow, 258
 - working detail, 289-91
 - work instruction, 291-92
 - zone painting method, 89-93
- Planning phase, 252, 253
 - defined, 252
- Plasma arc pipe cutter, 139
- Plasma metal inert gas welding, 133, 134
- Plasma welding, 125
- Plate fitting, 176
- Platen, 188
 - flat block, 191, 192
- Platen/block categories, 191, 192
- Plate welding, 176-77
- Pneumatic abrasive tool, 155
- Pneumatic device, 186
- Political factors, 14-15
- Poppet, 171
- Position-dimension diagram, 351
- Power tool cleaning, 154-55
- Precipitation during welding, 126
- Press brake, 121, 141
- Pressure blaster, portable, 154
- Primer painting, 90-92
- Problem area, 56-57
- Process analysis, 324
- Process lane, 60, 189-94, 234
 - categories, 141
 - cells, 277
 - curved panel block, 277
 - defined, 189, 276
 - facility layout, 190, 191-92
 - flat panel block, 277
 - hull construction, 276
 - loading, 193-94
 - outfit, 193
 - physical, 189-93
 - platen/block categories, 191
 - shop organization, 276
 - stages, 277
 - virtual flow, 373
- Process standard, 55
- Process time, 257
- Procurement
 - material, 305-14
 - material list, 313-14
- Product aspect, 56, 69
- Production, 8, 63-66
 - cost, 31
 - design, 222-44
 - facility, 175
 - function, 35
 - material, 303-5
 - output, 44
- Production control, 298-302
 - defined, 252
 - functions, 298
 - integration, 252-53
 - man-hour expenditure, 298
 - production progress, 298-99
 - productivity index, 299-302
 - zone-to-system transposition, 302
- Production control department, 221
- Production line, 60
- Production organization
 - craft, 163
 - mass production, 163
 - process, 162
 - product, 163
 - semi-process, 163
- Production period, optimum, 43
- Production planning
 - modules, 278-79
 - standards, 278-79
- Production planning flow, hull construction, 286
- Production progress, 298-99
 - hull construction, 299
- Production rate, 31-33, 41-43
 - adjusted, 31
 - completion stage, 31
 - optimal, 43
 - original, 44
- Production rate curve, 32, 33
- Production scheduling flow, hull construction, 287
- Production service, 188-89
- Productivity, 5, 28-29, 82, 229-32
 - block assembly, 296-98, 299-302
 - electrical assembly, 299-302

- erection, 299-302
- foreign, 29
- Japanese shipyard, 29
- low, 51-53
- machinery outfitting, 229-32
- parts fabrication, 299-302
- parts fabrication shop, 295
- resources, 57-59
- standardization, 228
- subassembly, 229
- subassembly section, 296
- time, 57-59
- work circumstance quality, 57-59
- Productivity control group, 301-2, 303
- Productivity index, 257, 258, 299-302
- Productivity value, 69
- Product orientation, 55
- Product-oriented construction. group, 48
- Product-oriented work breakdown structure, 31, 54-55, 61
 - assembly, 55
 - fabrication, 55
 - hull construction, 55
 - outfitting, 55
 - painting, 55
 - pipe piece family manufacture, 93-104
 - planning, 61-67
 - resources, 55
 - value analysis, 57-59
 - work package classification, 55-57
 - zone construction method, 67-93
- Product resource, 69
 - definitions, 55
- Product work breakdown structure, 50
- Profile cutter, 120
- Program Evaluation and Review Technique (PERT), 253-56
- Progress, 32, 34
- Progress curve, 32, 33
- Project management, 8
- Pulldown, 184
- Purchase order specification, format standardization, 240
- Purchase specification, 264-66
- Purchasing, 8, 310-12
- Push-pull jack, 185

Q

- Quality adjusted labor, 35
- Quality assurance, 8, 158-59, 319
 - outfit process, 159
 - steel process, 158-59
- Quality control *See* Accuracy control

R

- Range
 - random sample, 321-22
 - standard, 325
- Red hot heating, 135
- Register of Shipping of the USSR, 14

- Registro Italiano Navale, 14
- Regulatory agency, 13-14
 - areas covered, 13-14
- Repair approach
 - commercial, 362-64
 - critical path, 371
 - facilities, 361, 366, 367-68
 - military, 364-66
 - quasi-commercial, 366
 - planning of, 368-84
 - planning documents, 375, 376, 377
 - product-oriented, 375-82
 - product work breakdown structure, 371, 373
 - scheduling, 371, 372
 - systems-oriented, 371-72
 - vs. new construction, 373, 396-98
 - virtual flow lane, 373
 - zone-oriented, 372-375

- Repair industry, 20-21

- Required output

- changes, 38-39
- cost, 38-39
- shift, 38-39

- Requisition plan, 290

- Requisition process

- development, 309, 311
- functional flow, 309, 311

- Residence time, 126

- Resource market, 23-25

- Resource utilization, 32

- Resource utilization rate, 33

- Rework, 344

- Rigger/crane operator, 13

- Rigging, 148-49

- Rip-out, 366, 381

- Risk-aversion technique, 18

- Riveting, 161

- Robot, 244

- Roll-on/roll-off ship, 9

- Rotary wire brush, 155

- Rough cutting plan, 290

- Round component roll, 120

S

- Sampling, 320

- Scaffolding, 149-50

- Scatter, 321

- Schedule tracking meeting, 292

- Scheduling

- basic, 270-71, 279-84
- block assembly, 296
- conversion, 371, 372
- coordination, 52
- cycle, 271, 274
- defined, 252, 270
- design, 261-67; sequence, 263
- detail work instruction, 284-93
- erection shop, 298
- feedback, 67
- hierarchy, 270-271

- Scheduling (*continued*)
 - hull construction, 275
 - integrated, 63
 - integration, 252-53
 - major detailing, 288-89
 - master outfitting, 272
 - milestone, 272
 - mold loft, 226, 294
 - monthly, 273
 - network, 253
 - overhaul, 371, 372
 - overview, 257-271
 - parts fabrication shop, 294-95
 - repair, 371, 372
 - shop-level, 293-94
 - slippage, 33
 - subassembly section, 296
 - weekly, 273
 - working, 291
 - work instruction, 272
 - zone outfitting, 270
- Sea trial, 159
- Seam welding, 176
- Self-check, 336
- Semi-block assembly, 73-74, 76, 77, 79, 80
- Shaft, installation, 138
- Shears, 117
- Sheet metal cutter, 141
- Sheet metal mechanic, 13
- Shelf plate, 238
- Shell plate curving roll, 120
- Shewhart control chart, 321
- Ship
 - classification, 6, 8-11
 - definition, 6
 - types, 6, 8-11, 164-65; inboard profiles, 9-11
- Shipbuilding
 - definition, 6
 - history, 5
 - process, 3-6; stages, 3
- Shipbuilding activity timing schedule, 281
- Shipbuilding master schedule, 261, 262
- Shipbuilding model, 33-37
 - graphic analysis, 37-43
- Ship design group schedule, 266
- Ship design master schedule, 264-66
- Shipfitter, 13
- Ship production progress curve, 34
- Shipway, modular construction, 165
- Shipwright, 13
- Shipyards
 - building position, 171-73
 - European, 16
 - facility, 6-7, 12, 168-89
 - high-capacity in-line process, 164, 165
 - important features, 6-7
 - Japanese, 17
 - locations, 20
 - modular construction, 165-66
 - nationalized, 16, 168
 - 1960 to present, 163-68
 - organization, 7-8
 - pre-World War II, 162
 - receivership, 168
 - third-generation, 166, 167
- Shipyards layout, 6-7, 12, 170-71
 - conventional, 165-68
 - first-generation, 163
 - fourth-generation, 168, 169
 - historical perspective, 161-68
 - McNeill shipyard classification system, 161
 - product-oriented, 168
 - second-generation, 164
 - World War II to 1960, 162-63
- Shipyards planning overview, 257-59
- Shipyards selection, 4
- Shipyards worker, organization, 7-8
- Shop-level
 - planning, 293-94
 - scheduling, 293-94
- Shop organization, process lane, 276
- Shop priming, 156
- Shrinkage, 334, 355
- Shrinkage allowance standard, 356-58
 - elements, 356-57
- Side launching shipway, 172, 173
- Side launch system, 172, 173
- Sight line template, 339
- Single pass welding, 123, 125
- Siting, 168-89
 - factors, 168
- Skill dilution, 24
- Skilled labor, shortage, 23
- Skill level, 35
- Soldering, 134-35
- Specification, 197
- Spot heating, 135
- Stage, 57, 76-82
- Staging, 57, 149-50, 189
- Standard
 - basic, 229
 - classification, 229, 313
 - material, 312-13
- Standard deviation, 320
- Standard deviation analysis, 342
- Standard drawing, 229
- Standardization, 228-29
 - accuracy control, 332-35, 355
 - block, 228
 - component, 228
 - material list for manufacturing, 222
 - outfit unit, 228
 - productivity, 228
 - subassembly, 228
- Standard man-hour, 34, 35
- Standard range, 325
- Statistical analysis, work process requiring, 326
- Statistical control, 322-23

- Stay, 186
 - Steel, 107-10
 - brittle fracture, 110
 - choice, 112
 - corrosion resistance, 111-12
 - ductility, 110
 - fabrication, 164
 - fatigue strength, 111
 - grades, 112, 113-15
 - high-strength low-alloy, 112
 - notch toughness, 110-11
 - phase diagram, 107-10
 - properties, 110-12
 - requirements, 113-14
 - solidification process, 109-10; rapid cooling, 109-10; slow cooling, 109
 - strength, 110
 - stress-strain curve, 110, 111
 - transport, 164
 - types, 112
 - weldability, 112
 - Steel block, 255
 - Steel ship, classification, 14
 - Step-cut dog, 184
 - Stiffener setting, 178
 - Stiffener welding, automatic, 179
 - Stochastic network simulation management systems, 256
 - Strategic planning, 36
 - Stress-strain curve, 110-11
 - Strong back, 187
 - Structural assembly detail, 230
 - Structural material, 105
 - Structural strength, 14
 - Stud welding, 131-32
 - Subassembly, 4, 54
 - accuracy control, 337-39, 353-55
 - productivity, 229
 - Subassembly section
 - material control, 296
 - productivity, 296
 - scheduling, 296
 - Sub-block
 - assembly, 70-73
 - part concept, 70
 - Subcontracting, 310-12
 - Subcontractor, 24-25
 - Submerged arc welding, 130-31, 132
 - Subsidy, 14, 22
 - Substitutional solid solution, 106
 - Suez Canal, 165
 - Superstructure, 63
 - Superstructure block, 192
 - Superstructure outfit, 63, 65
 - Supertanker, 165
 - Supplier base, 25
 - decline, 25
 - Support service, 188-89
 - Surface preparation, 150-58, 179-81
 - force, 152
 - methods, 152
 - Surface transporter, 173
 - System, 56
 - System diagrammatic, 207-13
 - System plan, 211
 - Systems approach, 47
 - Systems-oriented work breakdown structure, 54
 - System-to-zone transposition, 62
- T
- Tacker/burner, 13
 - Tanker, 9
 - Taxonomy, 49
 - Technology, 28-29
 - Japanese shipyard, 29
 - U S vs. foreign, 28-29
 - Test, 159
 - combatant program contracts, 143
 - Thermite welding, 126, 134
 - Threaded device, 185
 - Title XI, 23
 - Tolerance, 324-25
 - end product, 324
 - interim product, 324-25
 - limit, 335
 - rework, 325
 - Torch tip, convergent type, 123
 - Total package procurement, 26-27
 - Total Transportation Systems, 174, 179, 180
 - Trade, 11-13
 - Trade skills, 11-13
 - Training
 - labor shortage, 23-24
 - Navy, 23
 - time required, 23-24
 - Transporter, self-propelled, 165
 - Trial, 159
 - Triangle heating, 135
 - Tug, 10
 - Tungsten inert gas welding, 132
 - Turnover, 24, 36
 - Turret press, 142
- U
- U S Coast Guard, 14
 - quality assurance, 158
 - U S Navy
 - construction program, 22
 - design, 3
 - quality assurance, 158
 - ship types, 164
 - ship work breakdown structure, 54
 - shipyard, apprentice training program, 23
 - systems-oriented structure, 54
 - training, 23
 - volume, 15
 - U S Public Health Service, quality assurance, 158

Underbidding, 38
Uniform work content, 34
Unit assembly, 83-84
 problem areas, 84
 stage, 84

V

Vacuum blaster, push mower type, 154
Vacuum saddle, 186
Value analysis, 57-59
Variance, 324
Variation, 319
 construction stage sources, 329
Variation merging, 323-24
Variation-merging equation, 324, 331-32, 332-33
Ventilation, 140-41

W

Waiting time, 45
Warehousing, 314-17
 facility, 174-75
 functional flow, 314, 316
Weapons system, 142-43
Web, 356
Wedge, 184
Wedge device, 184
Weekly schedule, 273
Welder, 13
Welding, 5, 123-34, 161 *See also* specific type
 aluminum, 116
 pipe, 139
 plate, 356
 repair, 178
 semiautomatic high-capacity, 166
 stiffener, 356
 types, 126-34
Welding process, penetrations, 123, 125
Weld metal, metallurgical effects, 126
Weld-on saddle, 184
Wet blasting, 155
Work access holes plan, 289
Work breakdown structure, 53-59
 product-oriented, 31
 system-oriented, 31
Work flow, 60
 level, 258-59
 planning, 258
Working detail, planning, 289-91
Working drawing, 63
Working piece treatments plan, 289
Working scheduling, 291
Work instruction
 computer-aided design, 248
 mold loft, 224

 planning, 291-92
 scheduling, 292

Work instruction master plan, 289
Work instruction package, 195
Work instruction plan, 218
 mold loft, 224
Work lot, 94-95
Work order, 52
 fire main, 52
Work package, 32, 58
 iterative development, 58
Work package number, 305
Work process, standards, 357-58
Work process lane, 63
Work standard, accuracy control, 333-35
Work unit, 189

Y

Yard plan, 197, 213
 mold loft, 223

Z

Zone, 56
 problem area, 76-82
 stage, 76-82
Zone construction group, 48
Zone construction method, 29, 53, 67-93
 design, 229-40
 fitting instruction, 232
 manufacturing instruction, 232
 material list for fitting, 232
 operation, 89
 pallet, 232
 planning, 68, 76
 test, 89
Zone outfitting method, 60, 76-89
 component procurement, 84
 manufacturing levels, 83
 objectives, 82
 operation, 89
 planning, 76-84
 product aspects, 82, 85
 scheduling, 270-71
 test, 89
Zone painting method, 60, 89-93
 manufacturing levels, 89-90
 objectives, 89-90
 paint systems, 90, 92
 planning, 89-93
 prerequisites, 89
 product aspects, 90, 91
 stage, 90
Zone planning, 29
Zone-to-system transposition, 62, 302